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TECHNICAL REPORT NO. 17

PROJECT TANK TRAP

A Field Evaluation of Nuclear Terrain Barriers

SEP 26 1969

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U. S. ARMY ENGINEER NUCLEAR CRATERING GROUP
Lawrence Radiation Laboratory
Livermore, California

and

LAND LOCOMOTION LABORATORY
U. S. Army Tank - Automotive Command
Warren, Michigan

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A Field Evaluation of Nuclear Terrain Barriers

PREFACE

This report presents the results of a joint research effort, designated Project TANK TRAP, conducted by the U. S. Army Engineer Nuclear Cratering Group (NCG) and the Land Locomotion Laboratory (LLL) of the Army Tank Automotive Center. This project, which was conducted at the Atomic Energy Commission's Nevada Test Site in 1964, evaluated the effectiveness of explosive produced craters as terrain barriers.

The participation of the Nuclear Cratering Group was accomplished under Department of the Army Research, Development, Test and Evaluation (RDT&E) Task 4A022601A880, "Military Engineering Applications of Nuclear Weapons Effects Research." The Land Locomotion Laboratory participated under DA Project No. 1D021701A045, "Vehicle Mobility Under Adverse Soil Conditions."

ABSTRACT

Project TANK TRAP was conducted to determine the capability of selected tactical vehicles to traverse craters typical of those which could be produced with Atomic Demolition Munitions (ADM). The vehicles included in the test program were the M-60 Tank, M-113 Armored Personnel Carrier, and an articulated two-unit general purpose vehicle called the POLECAT. Trafficability testing of these vehicles was performed in the SCOOTER crater, the JANGLE U crater, and Pre-SCHOONER BRAVO crater. The results of the research project indicate that: (1) craters formed in dry soil by the detonation of explosives at the surface or at very shallow depths of burst (down to approximately 20 $ft/kt^{1/3}$, do not present significant trafficability problems to tracked tactical vehicles; (2) craters formed at or near optimum depth of burst ($\sim$160 $ft/kt^{1/3.4}$) in dry soil are a trafficability obstacle to tracked tactical vehicles; and, (3) craters formed in hard rock, such as basalt, cannot be negotiated by tracked tactical vehicles without major modification of the crater and/or assistance by heavy duty equipment, either mobile or fixed.

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PROJECT TANK TRAP

INTRODUCTION

General

One of the potc tial military uses of Ato..aic Demolition Munitions (ADM) of prime significance to the tactical commander is the creation of terrain barriers to deny or delay access of enemy tactical vehicles through routes of advance. Many assumptions have been made concerning ability of tracked vehicles to negotiate craters produced by nuclear explosives. Speculation ranges from the opinion that tactical vehicles can negotiate any nuclear crater to statements that a nuclear crat·'r in any type material will constitute an obstacle to tactical vehicles.

To evaluate the effectiveness of nuclear craters as terrain barriers, the U. S. Army Engineer Nuclear Cratering Group (NCG) and the Land Locomotion Laboratory (LLL) of Army Tank Automotive Center participated in a joint research effort, designated as Project TANK TRAP, at the Nevada Test Site.

Purpose and Scope

The purpose of Project TANK TRAP was to determine the capability of selected tactical vehicles to traverse craters typical of those which could be produced with Atomic Demolition Munitions (ADM). The vehicles included in the test program were the M-60 Tank, M-113 Armored Personnel Carrier, and an articulated two-unit general purpose vehicle called the POLECAT The scope of the testing program did not include the use of engineering effort (earthmoving, bridging, surface stabilization, etc.) to assist the entry and exit of the vehicles. An M-88 Tank Recovery Vehicle was used to assist the vehicles in negotiating the craters, as required. It

was intended that the results of Project TANK TRAP would be used as a basis for more comprehensive research efforts in the field of crater negotiability to include determination of: (1) the most feasible method of improving trafficability of ADM craters; and (2) the construction effort required to render the craters trafficable.

Organization

Project TANK TRAP was conducted at the Nevada Test Site (NTS) during September, 1964.

Mr. William L. Harrison of the Land Locomotion Laboratory was Project Director and Major Bernard C. Hughes of the U. S. Army Engineer Nuclear Cratering Group was the Deputy Project Director. Figure 1 shows the Project Director's organization for the conduct of the research project.

BACKGROUND DATA

General Description of Nuclear Cratering Detonations

A nuclear detonation in soil or rock forms a crater by crushing, compacting, fracturing and displacing the medium. The material immediately adjacent to the explosion is vaporized and melted. Large quantities of soil or rock are thrown out of the ground. Some of the material falls on the ground outside the crater, while a very small portion of the finer particles is carried up in a large dust cloud and may come to rest at a considerable distance from the crater. The resulting crater is roughly hyperbolic in cross section.

A few basic definitions are required in order to understand the military engineering significance of the various crater zones resulting from a subsurface nuclear detonation. Figure 2 shows the cross section of a typical crater and the adjacent zones of disturbance. A brief description of these crater parameters is as follows:

Figure 1

Project Director's Organization, Project Tank Trap

TECHNICAL ADVISOR
Mr. Nat Davis (ERDL)

PROJECT DIRECTOR
Mr. W. Harrison (LLL)

DEPUTY DIRECTOR
Major B. C. Hughes (NCG)

TECHNICAL PROGRAM

VEHICLE CRATER MOBILITY
B. Hanamoto (LLL)

CRATER PROPERTIES MEASUREMENTS
Soil Strength Measurements - L. Martin (LLL)
Crater Profile Survey   -   R. Paul (NCG)

SUPPORT

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Radiological Safety
W. Day (NCG)
Operational Safety
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ENGR. & CONST.
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DOCUMENTARY PHOTOGRAPHY
Motion Picture - L. Guymon (LRL)
Still Photography - Lt. Boyle (APC)

LLL - Land Locomotion Laboratory Army Tank Automotive Center
NCG - U. S. Army Engineer Nuclear Cratering Group
ERDL - Engineer Research and Development Laboratory
LRL - Lawrence Radiation Laboratory
APC - Army Pictorial Center
DASA - Defense Atomic Support Agency

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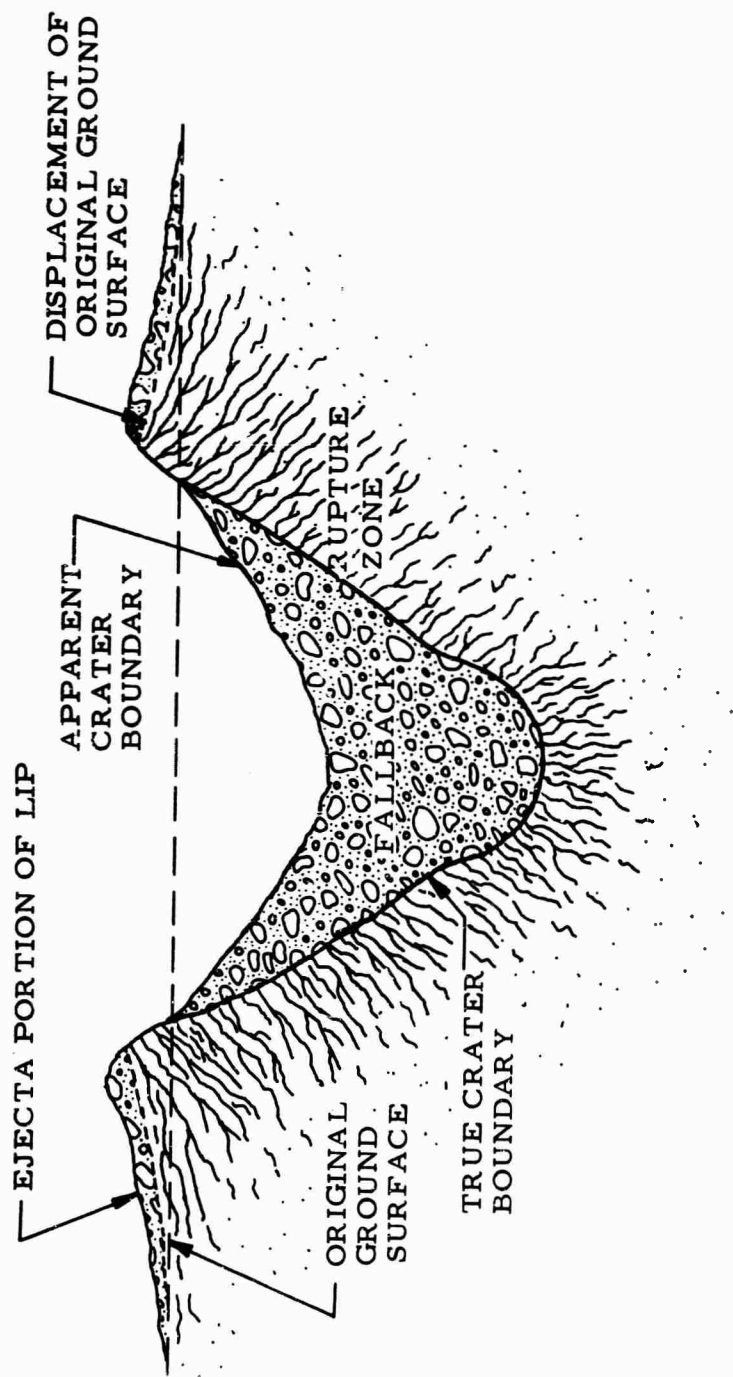
FIGURE 2. Cross Section of Typical Crater in Rock

DISPLACEMENT OF ORIGINAL GROUND SURFACE

RUPTURE ZONE

APPARENT CRATER BOUNDARY

FALLBACK

EJECTA PORTION OF LIP

ORIGINAL GROUND SURFACE

TRUE CRATER BOUNDARY

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The <u>apparent crater</u> is the portion of the visible crater which is below the preshot ground surface.

The <u>apparent lip</u> is the portion of the visible crater above the preshot ground elevation. The apparent lip of the crater is composed of two parts, the true lip and the ejecta. The true lip is formed by the upward displacement of the ground surface and the remainder of the apparent lip results from deposition of ejected material on the true lip.

The <u>visible crater</u> comprises the apparent crater and the apparent lip.

Effect of Depth of Burst on Crater Size and Shape

For detonations of a given yield, the size of the crater and shape of the crater formed varies greatly with the depth of burst of the charge. As the depth of burst increases crater dimensions increase to a maximum at some optimum depth, then decrease until a depth of burst is reached where no crater is formed. Figure 3 shows the variation in the craters formed from surface, shallow and optimum burial. It is evident from Figure 3 that the craters resulting from surface detonations have flat slopes and are relatively shallow in depth. Detonations in the vicinty of optimum depth of burst produce craters with relatively steep slopes.

Crater Dimensions

For a given material, crater size is a function of yield and depth of burst. Experimental results to date suggest that apparent crater dimensions should be proportional to the 1/3.4 power of the explosive yield. Using this empirical scaling law, cratering explosions at different yields can be correlated to establish the relationship between crater dimensions and depth of burst. This is done by normalizing all dimensions to those applicable to 1-kiloton by dividing the depth of burst and dimensions resulting from a given yield by $W^{1/3.4}$. A 1-kiloton (1 kt) nuclear detonation releases a

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(a)
SURFACE BURIAL

(b)
SHALLOW BURIAL

(c)
OPTIMUM BURIAL

LEGEND

Fallback

Rupture Zone

Plastic Zone
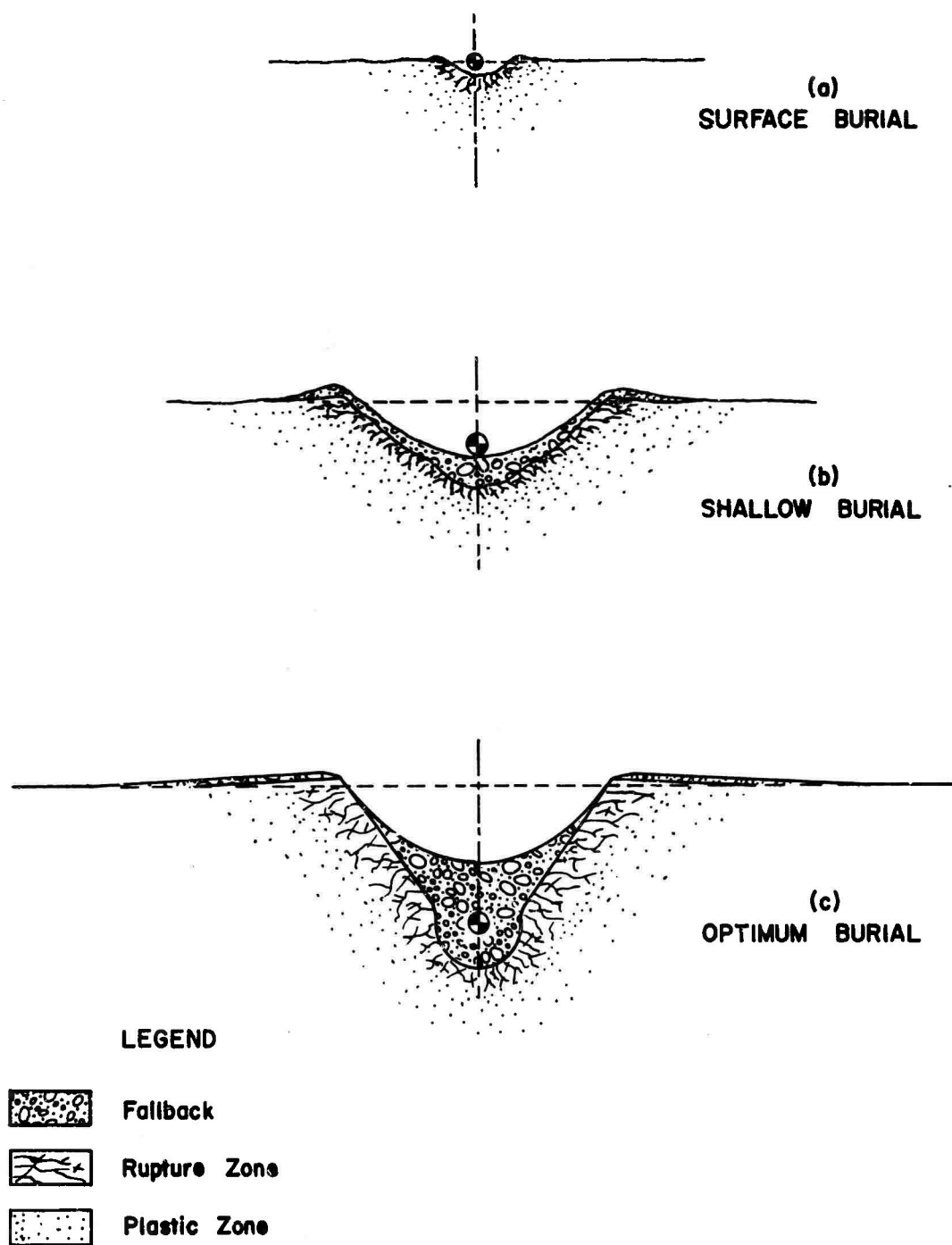
FIGURE 3. Typical Crater Profiles vs. Depth of Burst

total energy of 10^{12} calories, approximately the same energy released by 1 kt of TNT. The letter "W" is used to designate the energy yield of the explosion in kilotons (kt).

Figures 4 and 5 show the cratering curves from nuclear explosives in desert alluvium and hard, dry rock. All dimensions have been scaled to 1-kiloton using the 1/3.4 empirical scaling law.

PROJECT DESCRIPTION

Description of Test Sites

General

Project TANK TRAP was conducted in Areas 10 and 18 of the Nevada Test Site (NTS). Specific craters in which the vehicle trafficability study was conducted are described in Table 1.

TABLE 1

Description of Test Craters

Code Name	Cratering Medium	Yield Kiloton	Depth of Burst ft(ft/kt$^{1/3.4}$)	Radius, R_a, ft	Depth, D_a, ft	Lip Height ft	Slope Angle
SCOOTER	Alluvium	0.5/HE	125 (153)	155	75	12.5	30-35%
JANGLE-U	Alluvium	1.2/NE	17 (16)	130	53	8	20-32%
Pre-SCHOONER BRAVO	Basalt	.02/HE	51 (160)	49	25	9	27-30%

The original plan included the DANNY BOY basalt crater (0.42kt emplaced at 110 feet DOB) and the Pre-BUGGY Row H alluvium crater (13-1000 pound chemical explosives detonated in a row at near optimum depth of burst and at varying spacing). The vehicle testing results in the pre-SCHOONER BRAVO crater indicated it would be unsafe to attempt entry and exit of the DANNY BOY crater and it was felt that no additional information concerning trafficability

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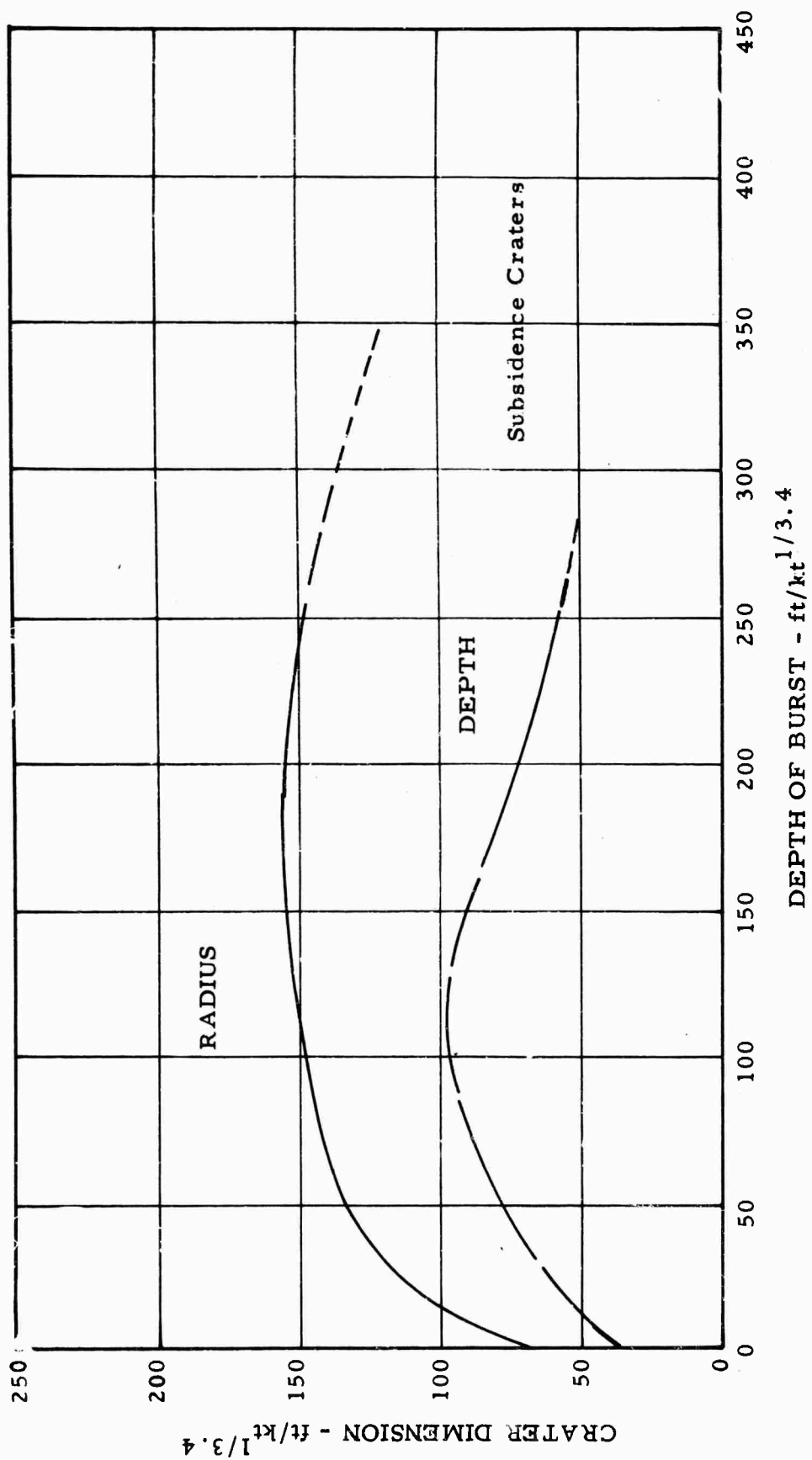
FIGURE 4. Apparent Crater Dimensions vs. Depth of Burst for Dry Soil

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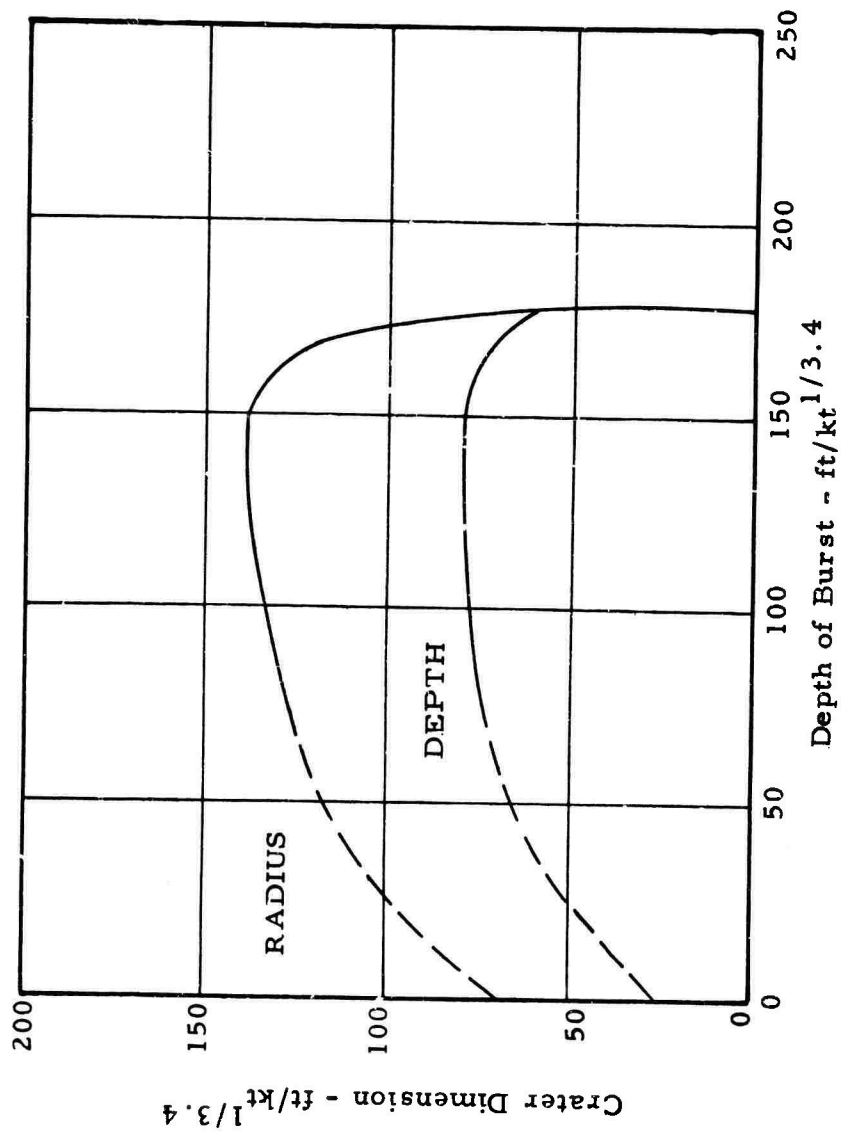
FIGURE 5. Apparent Crater Dimensions vs. Depth of Burst for Hard, Dry Rock

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of rock craters cou'd be obtained by so doing. A view of the planned
entry and exit slope of the DANNY BOY crater is shown in Figure 6. After
observing vehicle testing operations in the SCOOTER and JANGLE-U craters,
it was decided that the Pre-BUGGY Row H crater (average radius - 23 feet,
average depth, 13 feet) was too small to obtain meaningful test results.
Vehicle testing, therefore, was limited to the SCOOTER, JANGLE-U
and Pre-SCHOONER BRAVO craters. These crater sites were selected
for the vehicle trafficability study for the following reasons:

1. The craters are representative of those that could be produced by
Atomic Demolition Munitions (ADM) detonated at very shallow depths of
burst (JANGLE-U) and near optimum depths of burst (SCOOT R and Pre-
SCHOONER BRAVO).

2. The media in which the craters were produced bracket a wide range
or materials that are encountered in nature (dry soil to hard rock) and,
therefore, the test results could be used to predict the performance of
tactical vehicles in several different types of material.

3. The Nevada Test Site offers fully developed and functioning opera-
tional facilities.

Description of Test Craters

SCOOTER Crater

The SCOOTER crater, located in Area 10 of NTS in the northern part
of Yucca Flat Basin, is typical of craters produced by bursts at or near
optimum depth in desert alluvium. The desert alluvium may be described
as a loose silt-sand-gravel mixture with densities ranging from 1.5 to 1.7
gm/cc. Particle size ranges from cobbles of 1 to 2 feet maximum dimen-
sions through gravel and sand to very fine rock flour.

The SCOOTER crater was formed in October, 1960, by the detonation
of 500 tons of HE at a depth of 125 feet (scaled depth of 153 ft/kt$^{1/3.4}$).

FIGURE 6

Planned Entry and Exit
Slope of DANNY BOY Crater

The SCOOTER crater has an average radius, at the original ground surface, of 155 feet and depth of 75 feet. The lip averages 12.5 feet in height. The crater slopes average 30 to 35 degrees, flattening slightly near the top and bottom of the crater (Figure 7). As is typical of craters produced by detonations at or near optimum depth, the slopes and bottom of the crater are covered by fallback material. This material is unsorted, very loose and lies at its angle of deposition. The cohesion of the fallback material as determined from field soils measurements ranges from 0 to 0.15 tons/sq. ft. and the angle of internal friction (ϕ) varies from 30 1/2° to 33 1/2°.

Since the formation of the SCOOTER crater in 1960, the wind has blown some of the fine sand and silt sized particles in the fallback material down the crater slope and deposited them at the base of the slope. Although this action has altered the properties of the slope material somewhat, the fallback material in the region of the crater rim remains quite loose and moves freely when disturbed. No crust or hardened surface has formed on the crater slopes.

JANGLE-U Crater

The JANGLE-U crater is typical of craters produced in alluvium by detonations at very shallow depths. JANGLE-U is located in Area 10 at NTS, several hundred yards from the SCOOTER crater. The alluvial material is essentially the same as that of the SCOOTER crater.

JANGLE-U was formed in November, 1951, by the detonation of a 1.2 kt nuclear device at a depth of 17 feet (scaled depth of 16 ft/kt$^{1/3.4}$). The JANGLE-U crater has an average radius at the original ground surface of 136 feet and a depth of 55 feet. The lip averages 8 feet in height. The crater slopes average 20 to 32 degrees. The crater slopes are uneven and

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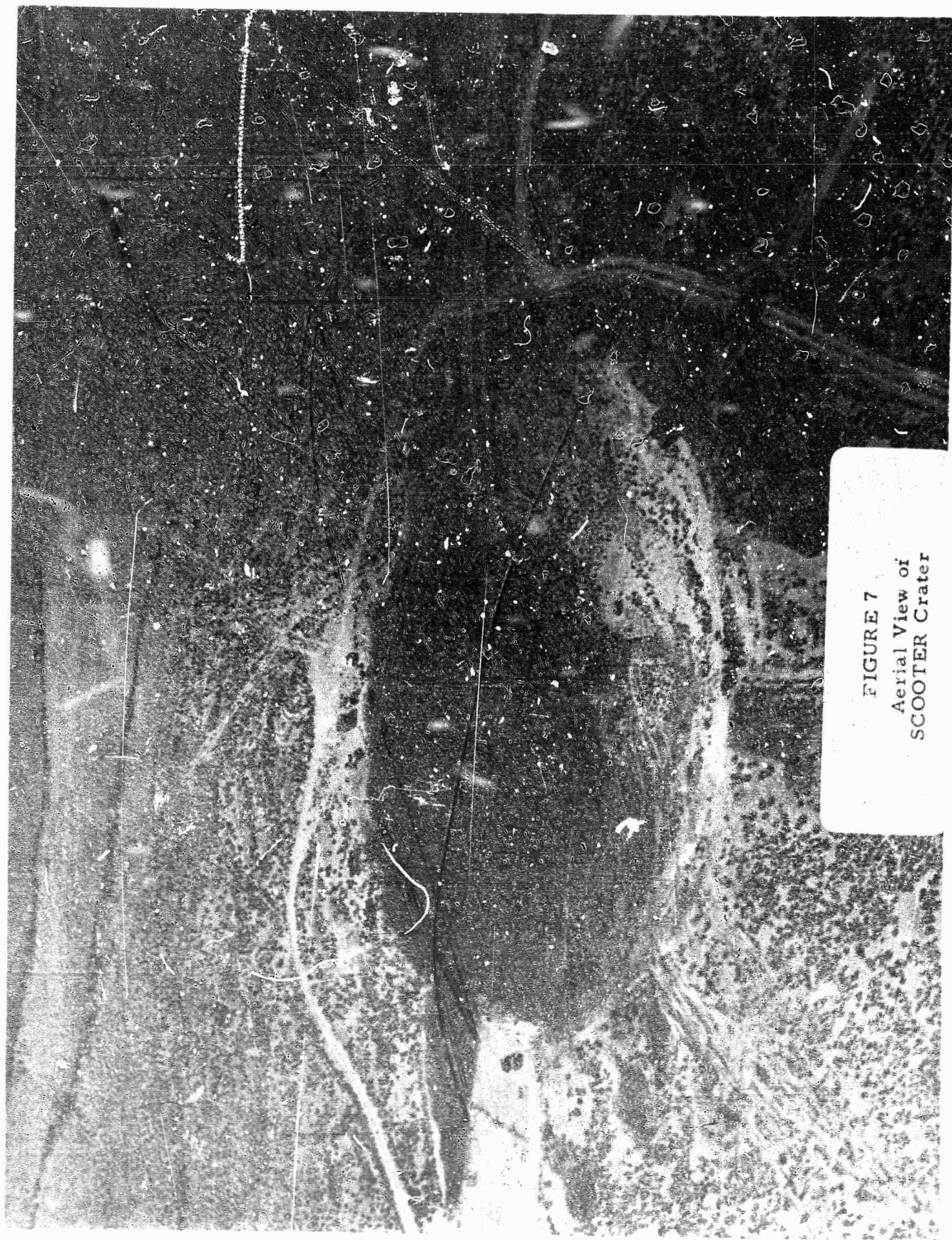
FIGURE 7
Aerial View of
SCOOTER Crater

are characterized by irregular benching (Figure 8). Field soils measurements indicated that the cohesion of the fallback material on the crater slopes ranges from 0 to 0.1 tons/sq. ft. and the angle of internal friction (ϕ) ranges from 32 1/2° to 36°. Exposures of the true crater are evident near the rim of the crater and fines are concentrated on the benched areas of the crater slope and at the bottom of the crater.

Since the formation of the JANGLE-U crater in 1951, the fallback material has been blown by the wind from the steeper parts of the crater slope and deposited on the benched areas and in the crater bottom. As a result of weathering and the removal of the loose sand and silt-sized particles from the slope surfaces, a crust has formed on the crater slopes.

Pre-SCHOONER BRAVO Crater

The Pre-SCHOONER Bravo crater is typical of craters produced by detonations at or near optimum depth in hard rock. The Pre-SCHOONER Bravo crater is located on Buckboard Mesa in Area 18 of NTS. The soil overburden on Buckboard Mesa consists of residual and aeolian sands and silts with large quantities of gravel and boulder sized fragments of vesicular basalt. This overburden averages three feet in depth.

The Pre-SCHOONER Bravo crater was formed in February 1964 by the detonation of 40,000 pounds of HE at a depth of 51 feet (scaled depth of 160 $ft/kt^{1/3.4}$). The crater has an average radius at the original ground surface of 49 feet and an average depth of 25.5 feet. The lip averages 9 feet in height. Crater slopes vary from 27 to 30 degrees with a general steepening in the lip area to 36 to 38 degrees. The fallback material consists of angular basalt fragments ranging from sand size to fragments with maximum dimensions of 12 feet. This fallback material results in very rough and

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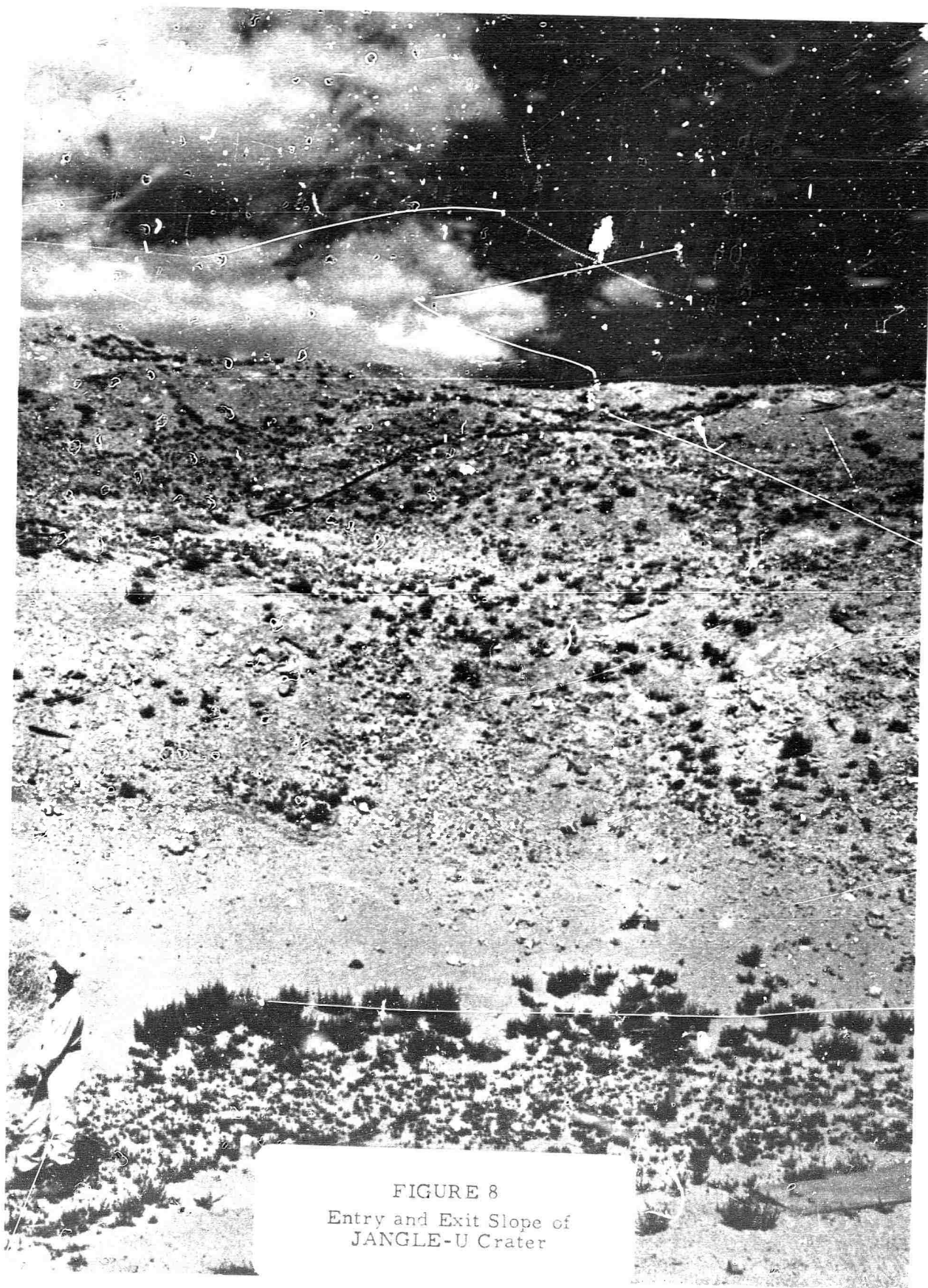
FIGURE 8
Entry and Exit Slope of
JANGLE-U Crater

irregular crater slopes (Figure 9).

There has been no alteration of the Pre-SCHOONER Bravo crater since its
formation. The slopes appear to be at the angle of repose for the fallback
material.

Description of Test Vehicles

The test vehicles used for Project TANK TRAP were the M-60 Tank,
the M-113 Armored Personnel Carrier, and a two-unit articulated tracked
vehicle known commercially as the POLECAT. With the exception of the
POLECAT, these vehicles are current tactical military vehicles. The
characteristics of the test vehicles are shown in Table 2.

Description of Vehicle Testing Procedure

In the alluvium craters (JANGLE-U and SCOOTER) the vehicle testing
program was accomplished in two phases. During the first phase each
vehicle was lowered into the crater, using the winch cable from the M-88
Tank Recovery Vehicle (VTR), and pulled up the crater slope by the winch
cable without vehicle power in order to determine the tangential force
required to pull the dead load of the vehicle up the crater slope. During
the second phase of the testing sequence, each vehicle attempted to negotiate
the crater slope under its own power. If the vehicle was not able to exit the
crater under its own power, the winch cable of the M-88 Tank Recovery
Vehicle was used to assist the vehicle and the extent of the assistance
required was recorded. Each vehicle was tested on at least two slopes
at each of the craters. The safety line from the M-88 VTR was attached
to the test vehicle at all times during the testing procedure. During that
phase in which this vehicle was negotiating the slope under its own power,
the winch operation of the M-88 VTR was controlled so that no assistance was
given the vehicle unless it was required.

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FIGURE 9
Aerial View of
Pre-SCHOONER BRAVO Crater

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TABLE 2

Characteristics of Test Vehicles

VEHICLE	GROSS WEIGHT	GROUND PRESSURE	VEHICLE TRACK		VEHICLE		
			WIDTH	GROUND CONTACT LENGTH	LENGTH	WIDTH	HEIGHT
POLECAT	9,100	2 psi	20 in	156 1/2 in	317 in	81 in	98 in
M-113 APC	19,755	7.3 psi	15 in	105 in	191-1/2 in	105-3/4 in	79-1/2 in
M-6 Tank	95,300	11 psi	28 in	166.7 in	273-1/2 in	143 in	126 in

The trafficability problem presented by the large boulders in the Pre-SCHOONER Bravo crater precluded determination of dead load measurements and this portion of the testing sequence was deleted. The M-60 Tank and the M-113 Armored Personnel Carrier were both lowered into the Pre-SCHOONER Bravo craters using the M-88 Tank Recovery Vehicle and each vehicle attempted to exit. Only one run was attempted with each vehicle. The POLECAT was not tested in the Pre-SCHOONER Bravo crater to prevent extensive damage to the vehicle.

Supporting Technical Programs

Soil Strength Measurements

Soil strength measurements of the undisturbed slope materials for the alluvium craters were taken prior to vehicle entry and exit in order to: (1) determine the characteristics of the soil media on the crater slopes; and (2) to provide data which would be of value to the Land Locomotion Laboratory in developing procedures for predicting vehicle performance on inclined configurations. The cohesion (c) and angle of internal friction (ϕ) of the material on entry and exit slopes were measured with a portable field type bevameter (Figure 10). The device is operated by first applying a normal pressure to the soil through the annular ring seated on the soil surface. The ring is then rotated until ultimate shear is recorded. A curve of shear stress vs. soil deformation is recorded on the X-Y plotter. The sequence is repeated at different normal pressures until a sufficient number of ultimate strengths have been recorded. Soil strength parameters, c and ϕ, are determined from these curves. A detailed explanation and results of the soil strength measurements program is given in Appendix A.

Tractive Performance Measurements

Baldwin-Lima Load Cells were inserted between the test vehicle and the

FIGURE 10

Use of Bevameter to Measure
Soil Values on Crater Slope

winch cable of the M-88 Tank Recovery Vehicle in order to: (1) determine

the tangential load required to pull the vehicle up the slope by winching only

(without vehicle power); and, (2) to determine the force (in pounds), if any,

required to assist the vehicles in existing the craters (Figure 11). Forces

on the load cell were recorded on a two channel Brush Recorder. Results of

this program are included in Appendices B and C.

Crater Profile Measurements

The profile along each entrance and exit route of the alluvium craters

was surveyed to determine slope angles, distances and differences in elevations.

Profiles were surveyed using transit and stadia techniques. Alluvium crater

profiles are shown in Figure 12 and 13. Topographic maps were used to plot

the entry and exit profile for the Pre-SCHOONER Bravo crater. The profile

of the Pre-SCHOONER Bravo crater is shown in Figure 14.

Documentary Photography

The Project TANK TRAP testing program was documented using still and

motion picture photography. Personnel of the Army Pictorial Center, stationed

at NTS, provided the still pictorial coverage. Motion picture coverage was

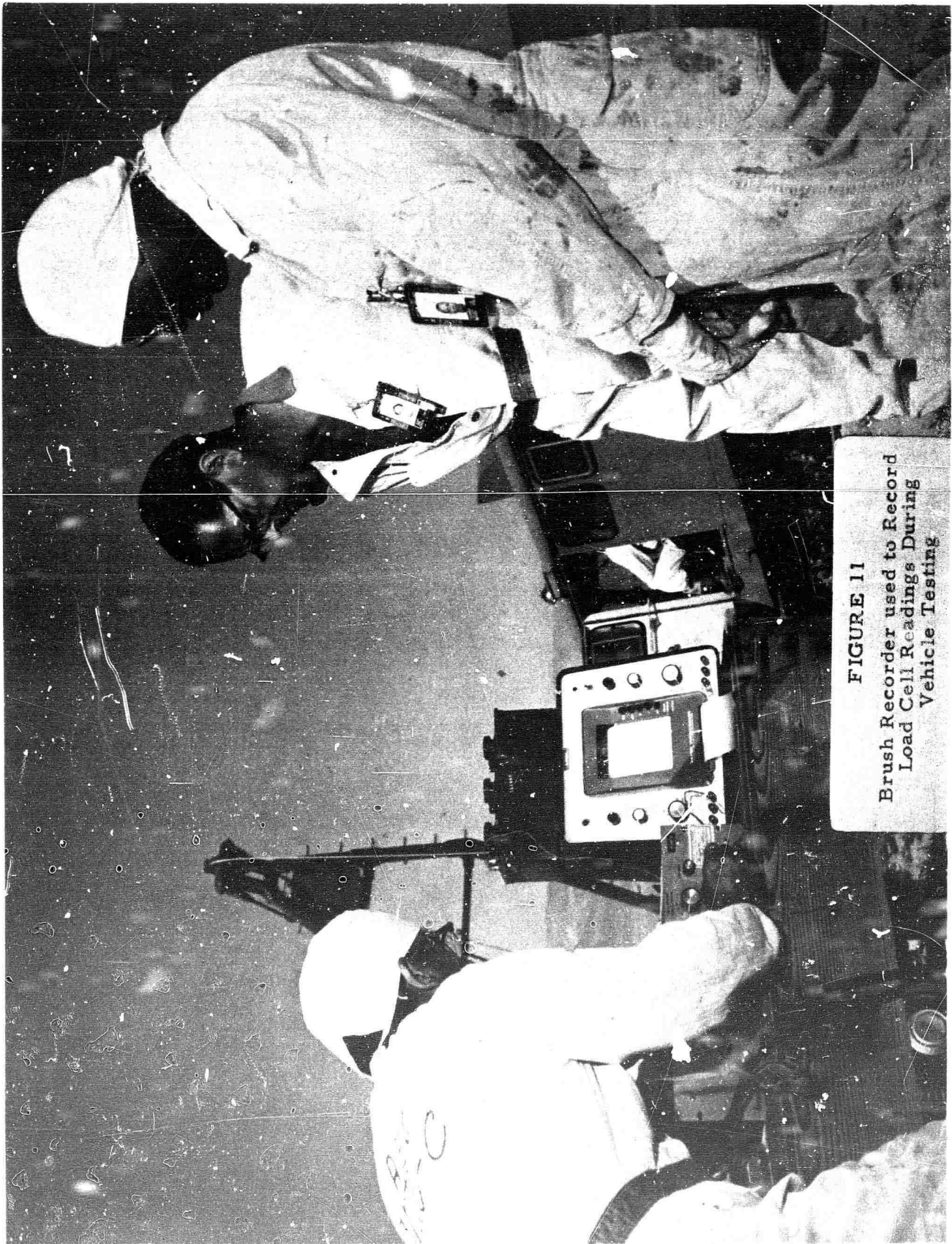provided by Lawrence Radiation Laboratory personnel.

FIGURE 11

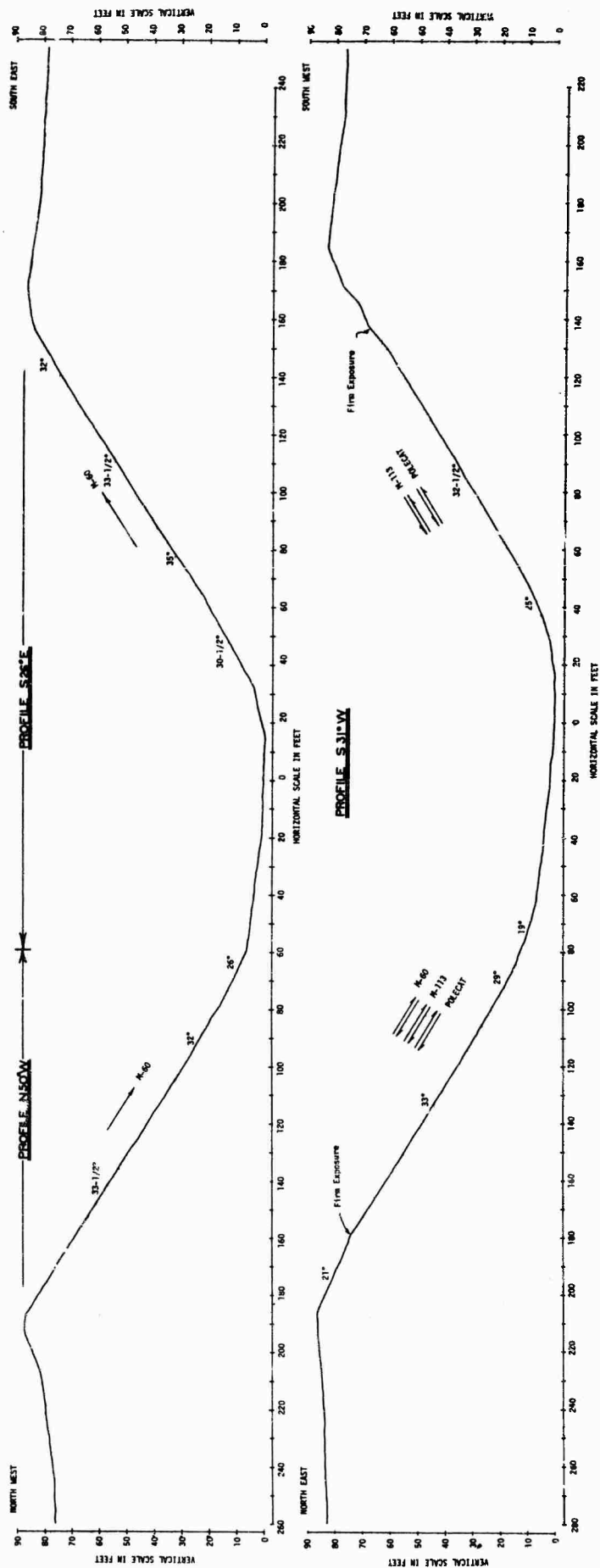Brush Recorder used to Record
Load Cell Readings During
Vehicle Testing
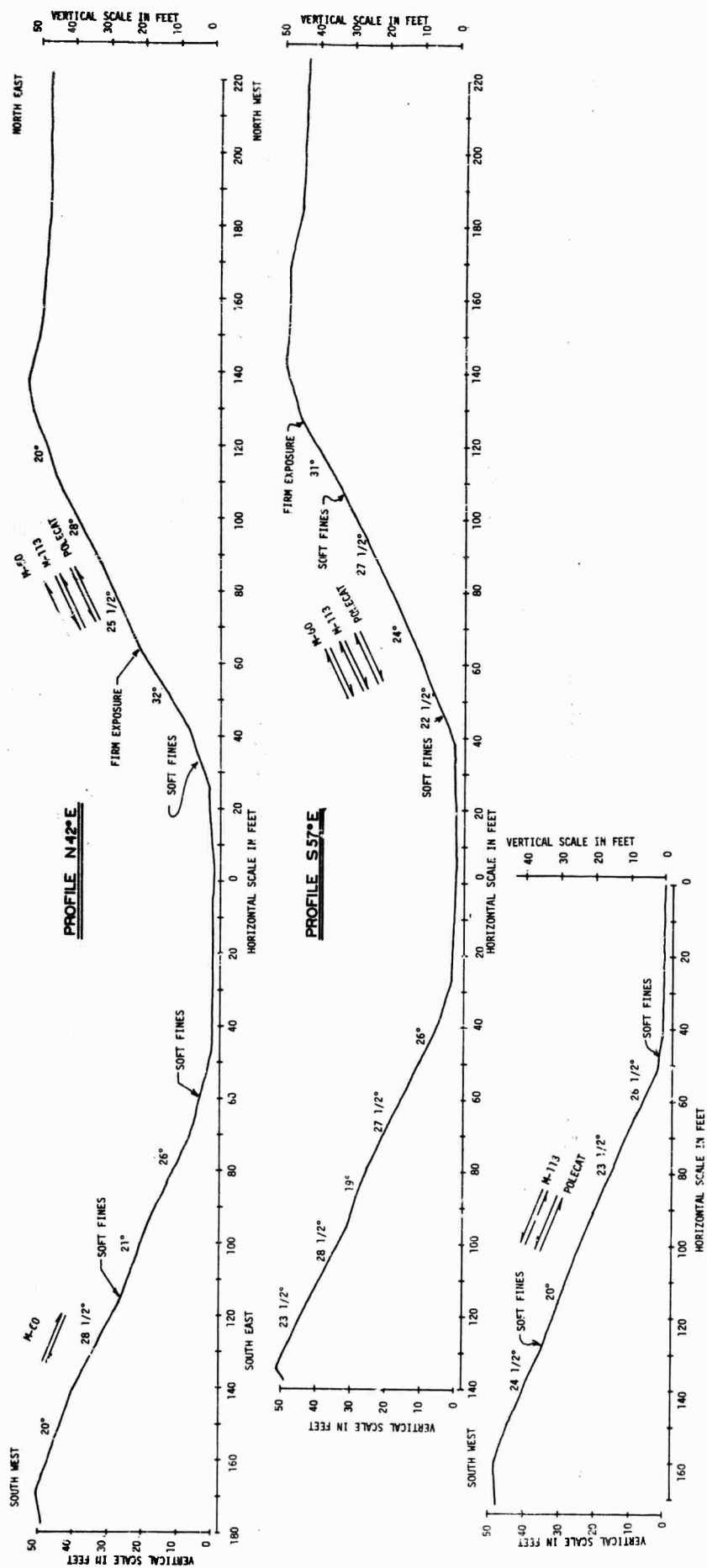
FIGURE 12. SCOOTER Crater Profiles

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FIGURE 13. JANGLE-U Crater Profiles

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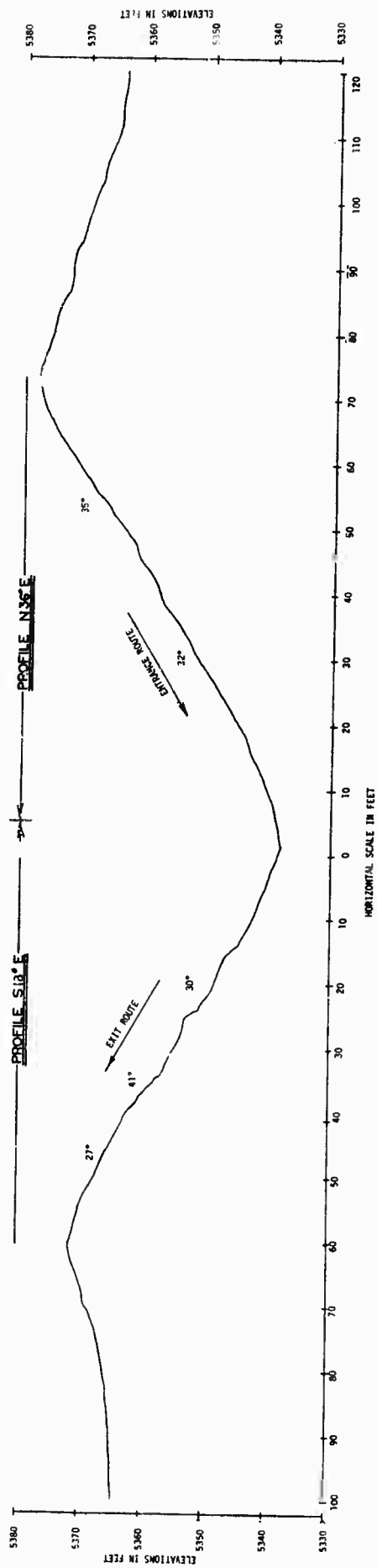
FIGURE 14. Pre-SCHOONER BRAVO Crater Profile

TEST RESULTS

Scooter Crater

General

During the first series of tests in the SCOOTER crater all three vehicles entered and exited on the NE slope along profile S31°W (Figure 12). In the second series of tests, the M-113 Armored Personnel Carrier (APC) and the POLECAT were operated on the Southwest slope of SCOOTER along Profile S31°W. The M-60 Tank entered the crater on the NW slope along Profile S26°E.

POLECAT Performance

Although intermittent load readings ranging from 0 to 500 pounds were recorded during the exit of the POLECAT from the SCOOTER crater, observation of the performance of the vehicle indicated that it could negotiate the crater without assistance. The load readings resulted from a lack of synchronization between the speed at which the winch was operating and the vehicle exit speed. There was considerable slack in the winch cable during the exit operation and the vehicle negotiated the slope with no apparent difficulty (Figure 15).

M-113 Armored Personnel Carrier (APC) Performance

The M-113 APC required winch assistance to exit the slopes of SCOOTER crater. The force required to assist in exiting ranges from 3,200 pounds to 4,000 pounds. The trim angle of the M-113 relative to the slope increased significantly while the vehicle was exiting under its own power.

M-60 Tank Performance

The M-60 Tank required assistance to exit each slope (Figure 16). Assisting forces of 2,000 pounds and 20,000 pounds were recorded during the

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FIGURE 15

Polecat Exiting the SCOOTER Crater

FIGURE 16

M-60 Tank Exiting the SCOOTER
Crater with Assistance from
M-88 VTR

two exiting operations. The slope requiring 20,000 pounds of force appeared to have a considerable layer of loose gravel on the surface (S26°E). This was not the case on the slope requiring 2,000 pound assistance. No other observations can be offered to account for the significant variation in required assistance on slopes with essentially the same inclination.

The winch on the M-88 Tank Recovery Vehicle did not have sufficient power to pull the M-60 Tank out of the crater without vehicle power from the tank. Although the winch has a rated capacity of 95,000 pounds it only developed approximately 40,000 pounds. The tangential force required to pull the dead load of the vehicle up the slope, therefore, could not be measured.

While lowering the M-60 into the crater on the NW slope of profile N50°W, during the final test sequence in SCOOTER, the winch failed. The M-60 free-wheeled into the crater from just above the half way point. The vehicle crossed the crater bottom to the opposite slope and rolled back to rest on the bottom. There was no apparent damage to the vehicle.

JANGLE U Crater

General

The crust on the crater slopes initially assisted the vehicles in exiting the crater, but the crust was easily broken and could not support the full vehicle weight. The fines which were deposited in the bottom on the crater constituted a soft area which reduced vehicle mobility.

POLECAT Performance

The POLECAT was tested on the Southwest slope of Profile N77°E, the Northwest slope of Profile S57°E and the Northeast slope of Profile N42°E (Figure 17). The POLECAT experienced no difficulty in exiting the JANGLE-U crater slopes.

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FIGURE 17

POLECAT Exiting the
JANGLE-U Crater

M-113 Armored Personnel Carrier Performance

The M-113 APC was tested on the same profiles as the POLECAT. It required winch assistance only on the Northeast slope of Profile N42°E. The 400 pounds of winch assistance was required to negotiate the bench which occurs in the profile at approximately half the distance up the slope. The M-113 APC tended to labor in the fines on the bench. This phenomenon was also noticeable on profile S57°E, but the vehicle was finally capable of exiting without winch assistance. The M-113 APC exhibited a high trim angle with reference to the slope angle while exiting the JANGLE-U crater (Figure 18).

M-60 Tank Performance

The M-60 Tank was capable of exiting the Southwest slope of profile N42°E without winch assistance (Figure 19). On the Northwest slope of Profile S57°E it required a winch assistance of 4,000 pounds to negotiate the finds in the bench area. No assistance was required throughout the remainder of the slope. On the Northeast slope of profile N42°E, the M-60 required an assisting force of 16,000 pounds during the first 1/4 of the slope. After clearing the bench area the M-60 required no winch assistance.

Pre-SCHOONER Bravo

General

Because of the large, angular, basalt rock which characterized the material in the ejecta field surrounding the Pre-SCHOONER Bravo crater, as well as the fallback material on the crater slopes, it was necessary to make a careful reconnaissance of possible routes of entry and exit through the crater prior to vehicle testing. The large boulders located on the crater slopes (Figure 20) limited the choice of entry and exit profiles to two or

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FIGURE 18
M-113 APC Exiting the
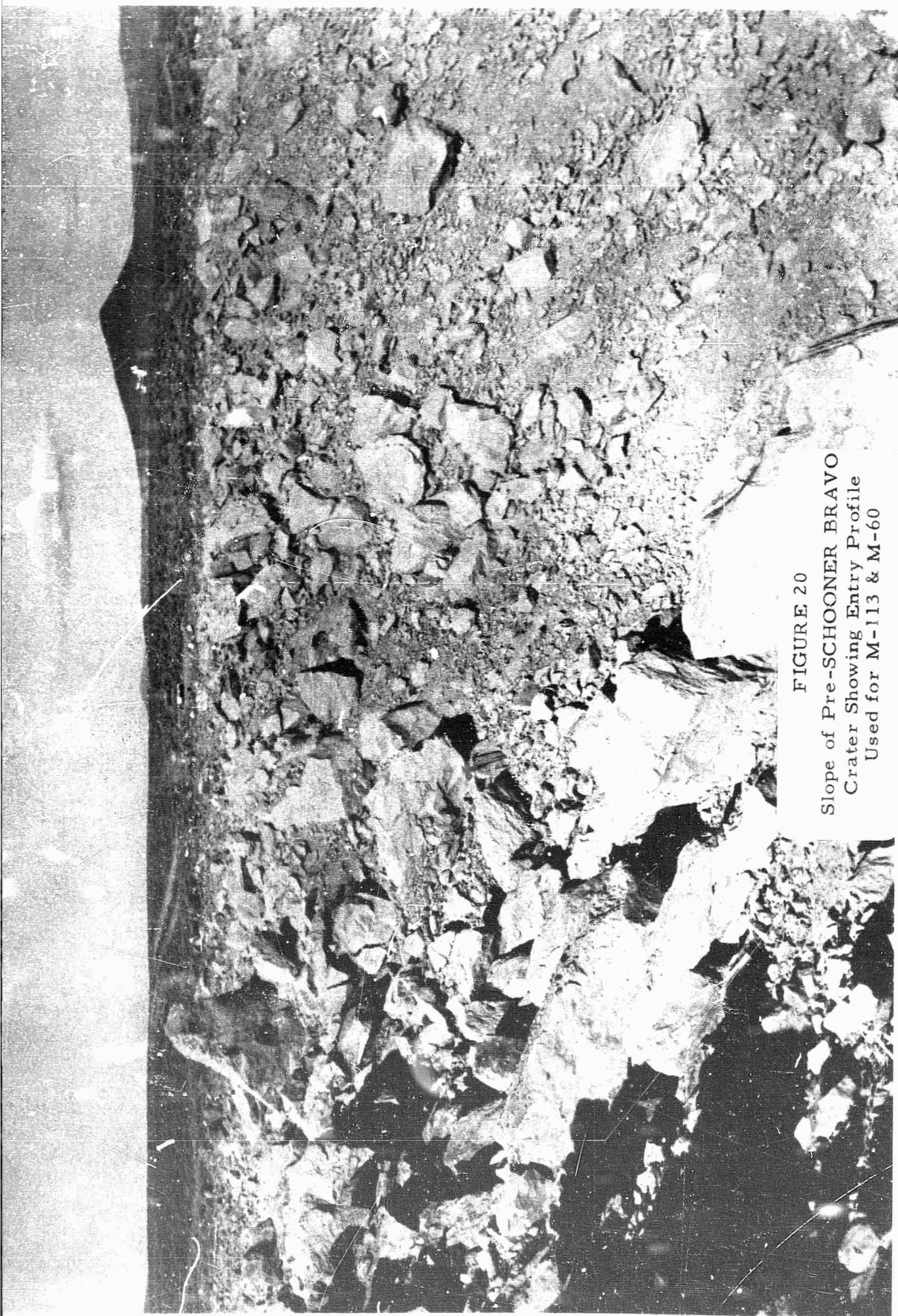JANGLE-U Crater

FIGURE 19

M-60 Tank Exiting the
JANGLE-U Crater

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FIGURE 20
Slope of Pre-SCHOONER BRAVO
Crater Showing Entry Profile
Used for M-113 & M-60

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three at the most. The profiles finally selected for testing the M-113
Armored Personnel Carrier and the M-60 Tank are shown in Figure 14.
The POLECAT was not tested in the crater because it was felt that its
sheet metal underbody would be severely damaged by the jagged edges of the
basalt ejecta and fallback material.

In order to reduce damage to the vehicles, a path was cleared through
the ejecta field with the blade on the M-88 Tank Recovery Vehicle. Figure
21 shows the cleared parth. The major portion of the lip was not altered
since an important part of the testing program was to determine the capability
of the vehicles to negotiate the crater lip.

Performance of M-113 Armored Personnel Carrier

From the edge of the approach path cleared by the M-88, the M-113
APC negotiated the lip of the crater under its own power with no difficulty
and was then lowered into the crater by the M-88 VTR. After the APC reached
the bottom of the crater the driver attempted to maneuver around the large
boulders in order to get into a position to exit but was unable to do so using
the power of the vehicle only (Figure 22). At this point in the testing sequence
it was determined that the APC could not maneuver into a favorable exit
position without assistance. By moving rocks ranging from 4 inches to 12
inches in diameter by hand and maneuvering the APC by means of the M-88
VTR winch it was possible to get the vehicle in a position to exit the crater.
While attempting to exit the crater under its own power the M-113 APC dis-
placed much of the rock surrounding the tracks. As a result, loose rock
became lodged in the track assembly. This loose rock tended to cause the
track to jump the drive sprocket. The M-113 APC was not able to exit the
slope without assistance and the M-88 VTR was used to winch the vehicle out
of the crater.

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FIGURE 21

Approach Path Through Ejecta
Field of Pre-SCHOONER BRAVO
Crater

FIGURE 22

M-113 APC Immobilized in
the Pre-SCHOONER
BRAVO CRATER

Performance of M-60 Tank

The M-60 Tank negotiated the crater lip and was lowered into the crater in essentially the same manner as the M-113 APC. The large boulders in the bottom of the crater prevented the M-60 from maneuvering into a favorable position for exit; and, consequently, rock was moved by hand to fill in the voids between the boulders so that the M-60 Tank could maneuver without becoming lodged on one or several of the boulders. The M-60 Tank attempted to exit the crater without assitance but the track simply rotated in place and the vehicle became embedded in the rock (Figure 23). As the M-60 Tank was attempting to exit the crater with assistance from the M-88 VTR winch, the right track jumped off the drive sprocket due to rocks becoming lodged in the track assembly system. Efforts to get the track back on the sprocket while the tank was in the crater were unsuccessful, and the vehicle was winched from the crater with only one track providing traction. Inspection of the right track and sprocket showed that the track system was damaged considerably.

Summary

Table 3 tabulates the results of the vehicle tests and soil measurements in the SCOOTER, JANGLE-U, and Pre-SCHOONER Bravo craters.

CONCLUSIONS

Based on the results of Project TANK TRAP it is concluded that:

1. Craters formed in dry soil by the detonation of explosives at the surface and at very shallow depths of burst (approximately 20 $ft/kt^{1/3.4}$) do not present significant trafficability problems to tracked tactical vehicles. This is primarily due to the fact that this type of crater has flat slopes and is relatively shallow.

2. Craters formed at or near optimum depth of burst (160 $ft/kt^{1/3.4}$) in dry soil are a trafficability obstacle to tactical tracked vehicles. The

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FIGURE 23

M-60 Tank Embedded in rock in
Pre-SCHOONER BRAVO CRATER

TABLE 3

Summary Tabulation of Test Results

CRATER	VEHICLE	PROFILE	SLOPE (Degrees)	SOIL MEASUREMENT C	SOIL MEASUREMENT φ	DEAD LOAD (lbs)	REQUIRED ASSISTANCE
SCOOTER	POLECAT	S31°W(NE)	33	0+	33.5	5,600	0 - 200
	POLECAT	S31°W(SW)	32.50	0+	30° - 33°	5,750	0 - 500
	M-113	S31°W(NE)	33	0+	33.5°	11,600	4,000
	M-113	S31°W(SW)	32.5	0+	30° - 33°	11,000	3,200
	M-60	S31°W(NE)	33°	0+	33.5°	NR*	2,000
	M-60	S26°E(SE)	35° - 33.5°	0+	30° - 33°	NR*	20,000
JANGLE-U	POLECAT	N77°E(SW)	20° - 26.5°	0 to 0.1	32.5° to 35°	4,500 to 5,600	0
	POLECAT	S57°E(NW)	22.5° to 31°	0+	33.5° to 36°	5,500 to 6,000	0
	M-113	N77°E(SW)	20° - 26.5°	0 to 0.1	32.5° to 35°	650 to 9,000	0
	M-113	S57°E(NW)	22.5° - 31°	0+	33.5° to 36°	8,400 to 9,200	0
	M-113	N42°E(NE)	20.0° to 32°	0+	33° ± .5	8,800 to 11,600	400
	M-60	N42°E(SW)	20° to 28.5°	0+	34 ± .5	44,000	0
	M-60	S57°E(NW)	22.5° - 31°	0+	33.5° to 36°	NR*	0 to 4,000
	M-60	N42°E(NE)	20.0° to 32°	0+	33° ± .5	NR*	16,000 to 10,000 to 0
Pre-SCHOONER BRAVO	M-113	S18°E(NE)	27° to 41°	N/A	N/A	NR*	NR*
	M-60	S18°E(NE)	27° to 41°	N/A	N/A	NR*	NR*

*NR - No reading.

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slopes of this type of crater are greater than the slopes of very shallow depth of burst craters.

3. Craters formed in hard rock such as basalt cannot be negotiated by tracked vehicles without major modification of the crater and/or assistance by heavy duty equipment either mobile or fixed. The random arrangement and size (ranging from several inches to several feet) of the rocks ejected by the detonation cause the primary trafficability problem. Visual observation of craters formed in basalt by detonation of explosives in the ADM yield range indicate that detonations at scaled depths of burst considerably less shallow than the Pre-SCHOONER Bravo depth of burst would also constitute formidable barriers to tracked vehicles.

4. A two-unit articulated vehicle such as the POLECAT is able to negotiate crater slopes in dry soil much more readily than tactical tracked vehicles such as the M-113 APC or the M-60 Tank. This is due primarily to the fact that the center of gravity of the two-unit vehicle lies forward of the rear unit (there is essentially no weight transfer between units of the articulated vehicle); and, consequently, the ground pressures at the rear of the second unit are considerably less than the rear pressures of a single unit tracked vehicle.

APPENDIX A

SOIL STRENGTH MEASUREMENTS AND DATA ANALYSIS

Soil strength measurements were obtained during all vehicle testing in soft soils. These soil measurements document the test conditions and furnish soil data which can be used for theoretical predictions of vehicle mobility. Based on the relative performance of different vehicles, the soil strength data can also be used for predicting the mobility of new vehicles.

Normally two types of tests are conducted to measure the soil parameters which are the basis of our theoretical predictions of vehicle mobility. These tests are a vertical load-deformation test and a horizontal shear stress-deformation test. In Project TANK TRAP only the horizontal shear stress-deformation test was performed because this gives the soil parameters which determine vehicle tractive effort. The tractive effort was considered the prime factor in negotiating the slopes.

A Bevameter, which is a "portable shear device," (Figure 10), was used to perform the test. The recording instrumentation is not shown. The grousered annulus is loaded normal to the ground surface, rotated, and a shear stress-deformation curve results. The normal load is varied and several shear stress-deformation curves are recorded. The ultimate values of the shear stress-deformation curves are plotted as a function of normal pressure, σ. These results will produce a plot of Coulomb's equation, $S_s = c + \sigma \tan \phi$, where c is the cohesion, and ϕ is the angle of internal friction of the soil and S_s is shear stress. Figures A-1 and A-2 are examples of data from JANGLE-U crater. Figure A-1 is the raw data and Figure A-2 is the graph of Coulomb's equation for these data.

A-1
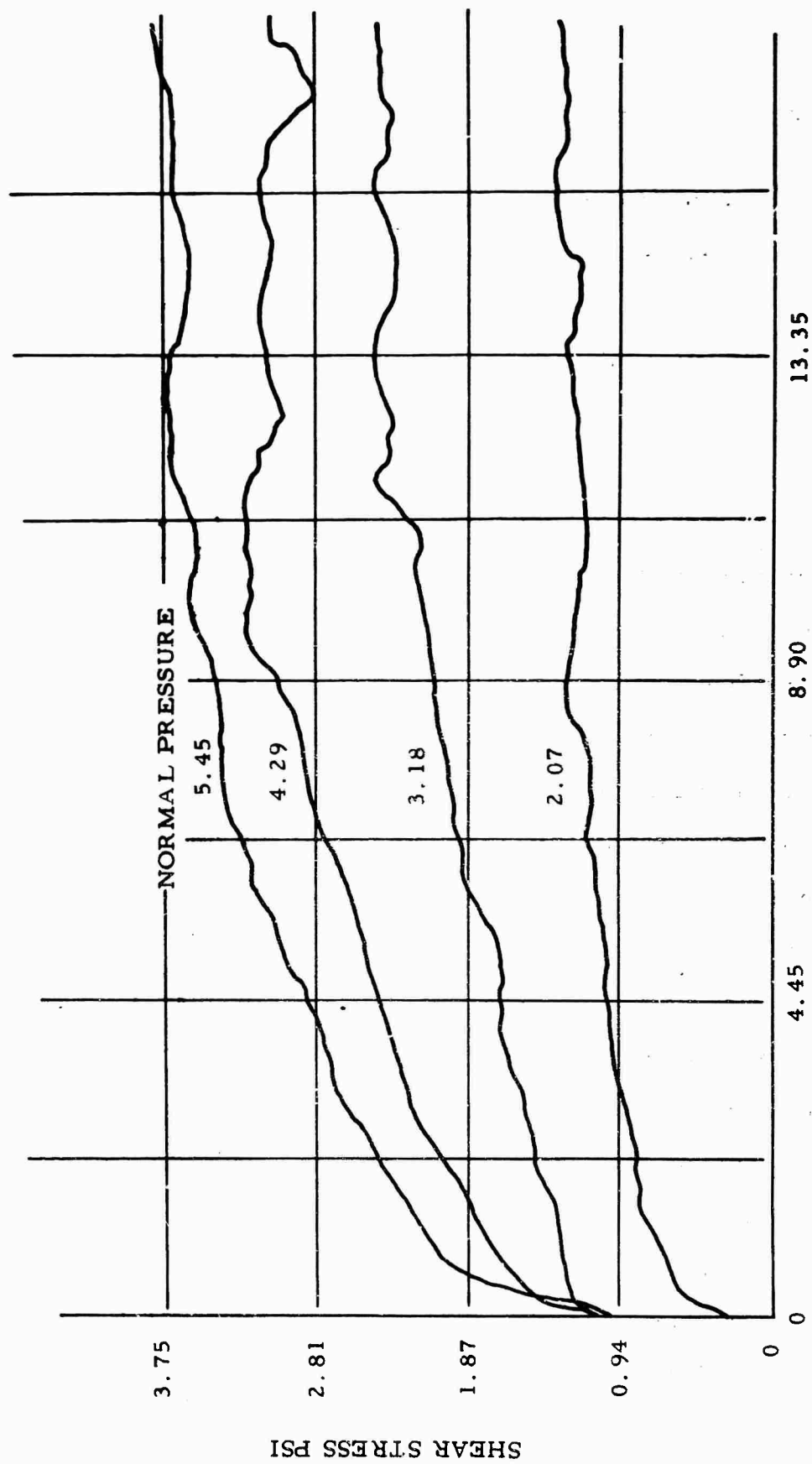
FIGURE A-1. JANGLE-U Shear Stress Deformation Curves
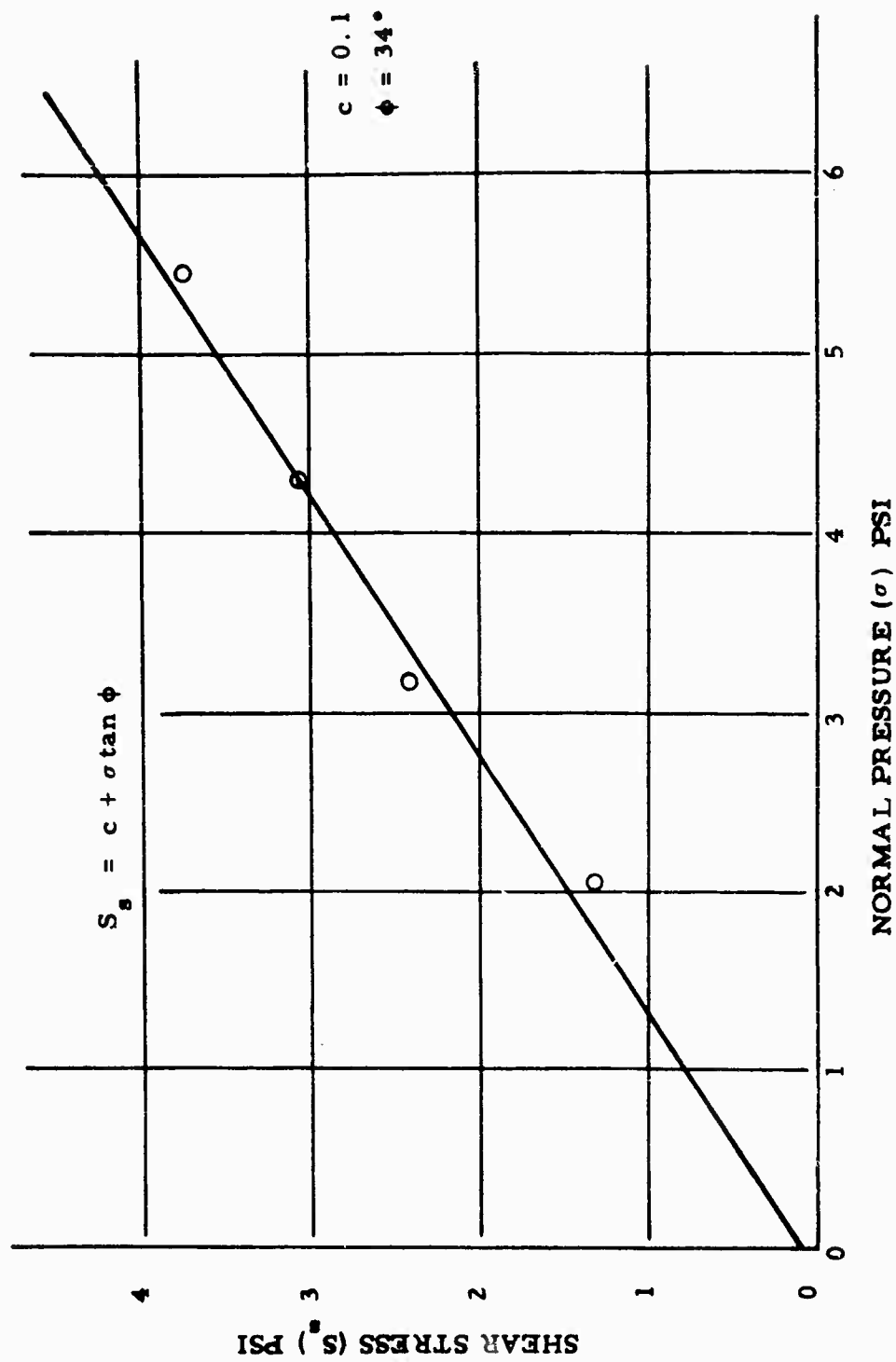
FIGURE A-2. Plot of Coulomb's Equation

A-3

Tables A-1 and A-2 are a tabulation of the soil measurements during tests in SCOOTER and JANGLE-U craters.

These soil strength properties are necessary for the prediction of vehicle mobility with the equations and tehniques developed by the Land Locomotion Laboratory. The soil properties c and ϕ are used in Appendix C of this report to determine the gross tractive effort that can be developed in a soil by any given vehicle, knowing the vehicle characteristics.

TABLE A-1

SOIL VALUES MEASURED IN SCOOTER CRATER

Location	Cohesion c	Angle of Internal Friction φ	
	psi	tan φ	degrees
S26E	0	0.65	33.0
SE	0	0.584	30.3
	0.1	0.633	32.3
	0	0.61	31.7
S31W	0.1	0.66	33.5
NE	0.15	0.658	33.4
	0.1	0.633	32.3

TABLE A-2

SOIL VALUES MEASURED IN JANGLE-U CRATER

Location	Cohesion c	Angle of Internal Friction φ	
	psi	tan φ	degrees
N42E	C	0.66	33.5
NE	0	0.637	32.5
S57E	0	0.66	33.5
NW	0	0.726	36.0
N77E	0	0.751	35.5
SW	0.1	0.635	32.4
N42E	0	0.685	34.4
SW	0	0.66	33.5
Virgin	0	0.66	33.5
Area	0	0.65	33.0

APPENDIX B

GROUND PRESSURE DISTRIBUTION

One of the basic requirements for the prediction of vehicle mobility is an understanding of the ground pressure exerted by the vehicle on the soil. The ground pressure determines the motion resistance of the vehicle as well as the tractive effort. Therefore, before theoretical predictions can be made on the mobility of vehicles through craters, the following method is used to calculate the ground pressure of these vehicles on the slopes.

The ground pressure distribution under the tracked vehicles tested is assumed to be trapezoidal in shape when the vehicle is on a slope. The geometric shape of the trapezoid is shown in Figure B-1 where γ is the slope angle.

A free body diagram with the forces required for static equilibrium is shown in Figure B-2. For static equilibrium $F = 0$, therefore, $R = W$ and $r = y$. The general formula for the location of the centroid of a trapezoid is:

$$r = \frac{h(2a + b)}{3(a + b)} = y \tag{1}$$

where a and b are the parallel sides and $h = 1 =$ trapezoid height.

For a given slope γ, and knowing the vehicle weight and dimensional characteristics, equation (1) can be solved for unknowns "a" and "b" as follows:

$$a = \frac{h^2 \tan \gamma - 3yh \tan \gamma}{(6y - 3h) \ \sin (90 - 2\gamma)} \tag{2}$$

$$b = \frac{h \tan \gamma + a \sin (90 - 2\gamma)}{\sin (90 - 2\gamma)} \tag{3}$$

The ground pressure multiplied by the area of distribution must be equal to the weight of the vehicle. This can be reduced to a two-dimensional problem by taking the vehicle weight per unit track length. This assumes an equal ground pressure
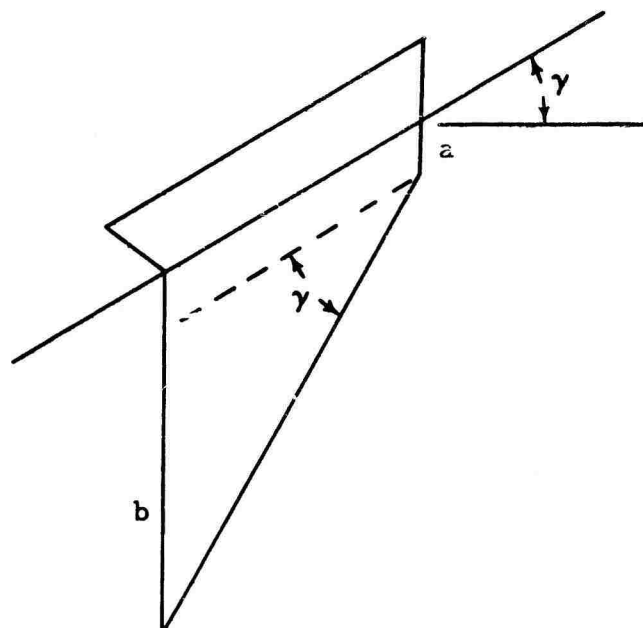
FIGURE B-1.

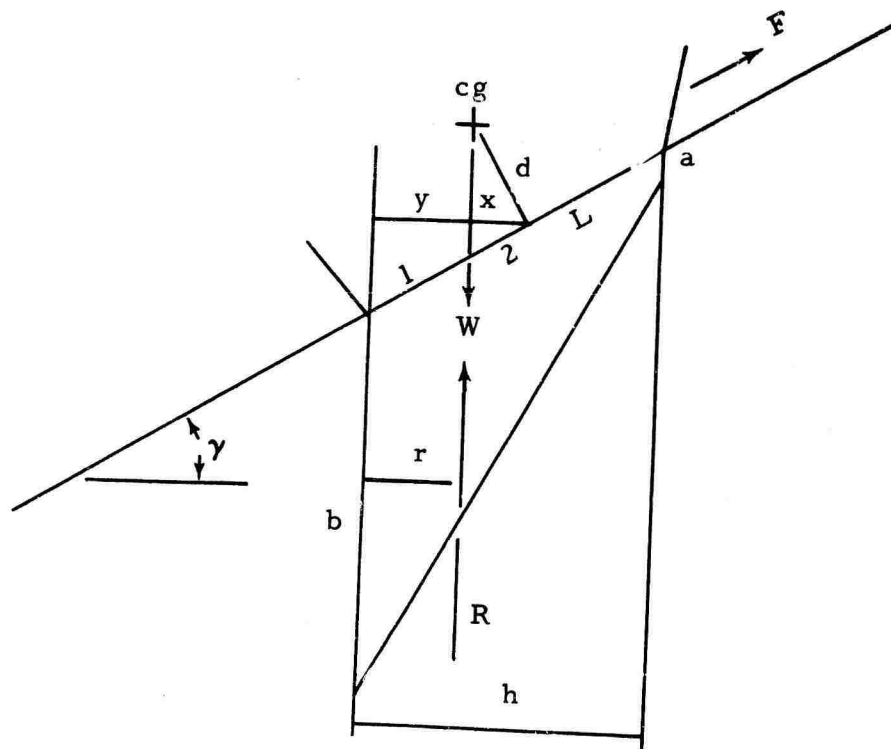Ground Pressure Distribution Under Tracked Vehicle

FIGURE B-2. Free Body Diagram

across the track width which is a simplification;

$$A = \frac{\text{Pounds}}{\text{Unit Track width}} = \frac{\text{weight of vehicle}}{2 \times \text{track width}} \qquad (4)$$

The quantity $(a + b) = \frac{2A}{h}$ from the equation for the area of a trapezoid.

Therefore, the ground pressures at a and b (G. P.$_a$ and G. P.$_b$) can be calculated:

$$\text{G P.}_a = \frac{a}{a + b\left(\frac{2A}{h}\right)} \; ; \quad \text{G. P.}_b = \frac{b}{a + b\left(\frac{2A}{h}\right)} \qquad (5)$$

A sample calculation follows:

M-113 vehicle

$\gamma = 30°$

$W = 19,775$ lbs.

$d = 39.2$ in.

$l = 105$ in.

$h = l \cos \gamma = 105 \times .866 = 91.4$

$l_1 = 52$ in., $l_2 = 53$ in.

$y = l_2 \cos \gamma - d \sin \gamma = 53 \times 0.866 - 39.2 \times 0.5$

$y = 46 - 19.6 = 26.4$ in.

from equation (2):

$$a = \frac{h^2 \tan \gamma - 3vh \tan \gamma}{(6y - 3h) \left[\sin(90 - 2\gamma)\right]} = \frac{91.4^2 \times .577 - 3 \times 26.4 \times 91.4 \times .577}{(6 \times 26.4 - 3 \times 91.4) \quad \sin(90 - 60)}$$

$a = -10.7$ in.; therefore, the pressure distribution is not trapezoidal.

Also, since $r = y = 26.4$ for static equilibrium and

$h/3 = \frac{l \cos \gamma}{3} = \frac{91}{3} = 30.3 > 26.4$ then, the ground pressure distribution must

be triangular under the M-113 with the centroid of the area at $r = 26.4$ in.

This means the ground contact length must be $\frac{3 \times 26.4}{.866} = 91.4$ in. instead

of the 105 in. which is the contact length on hard level ground.

The weight distribution per unit width of the M-113 is

$$\frac{19,775 \text{ lbs.}}{2 \times 15} = \frac{660 \text{ lbs.}}{\text{unit width}}$$

Therefore:

$$b = \frac{2A}{h} = \frac{2 \times 660}{91.4 \times 0.886} = 16.6 \text{ psi}$$

This pressure distribution is illustrated in Figure B-3.

Figures B-4 and B-5 illustrate the ground pressure distribution on a 30° slope for the M-60 and POLECAT vehicles.
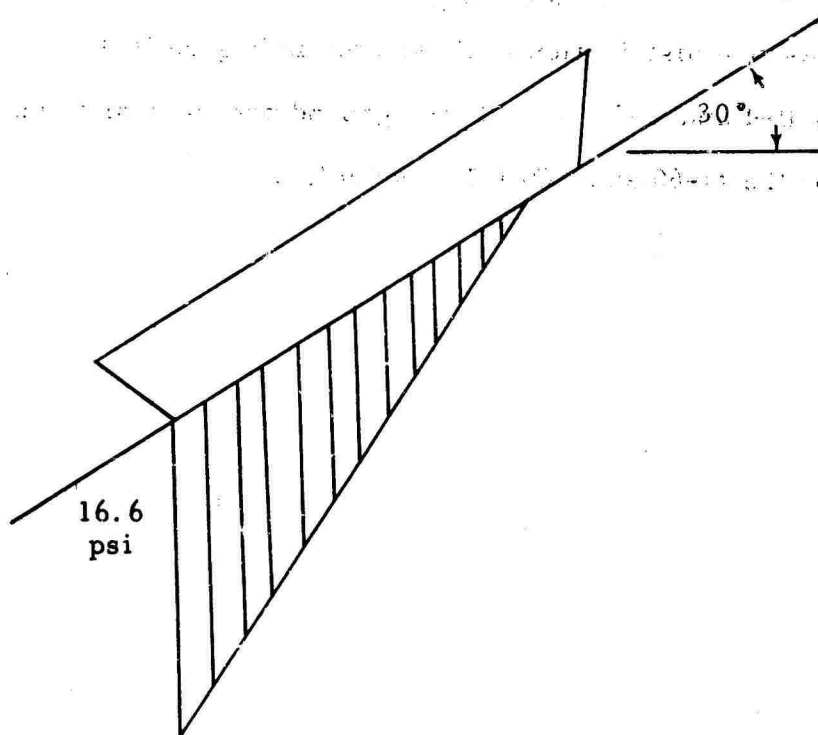
FIGURE B-3.

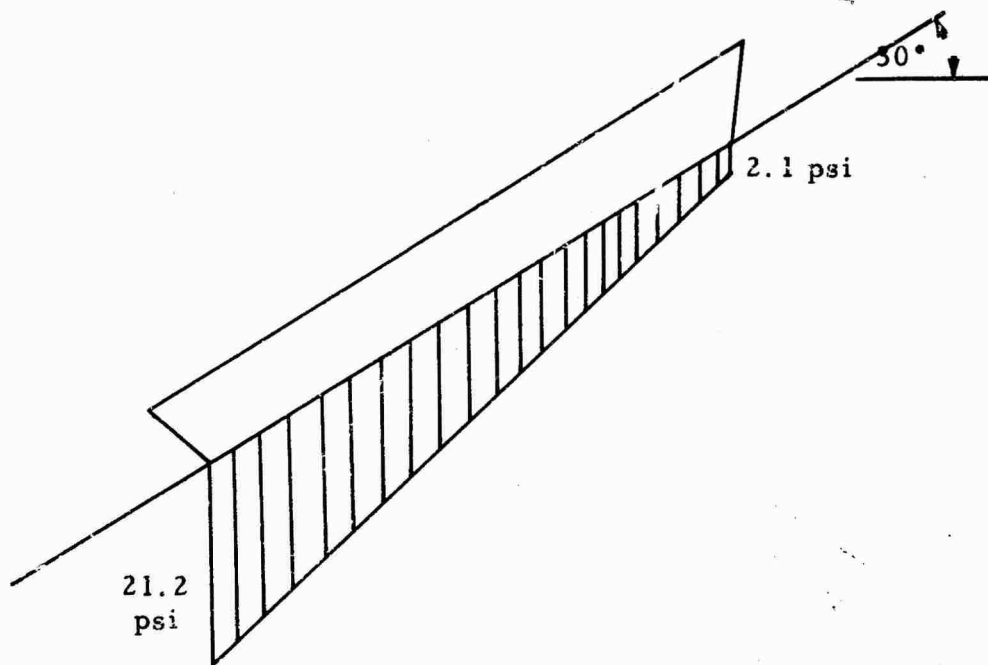Ground Pressure Distribution of M-113 on 30° Slope

FIGURE B-4.

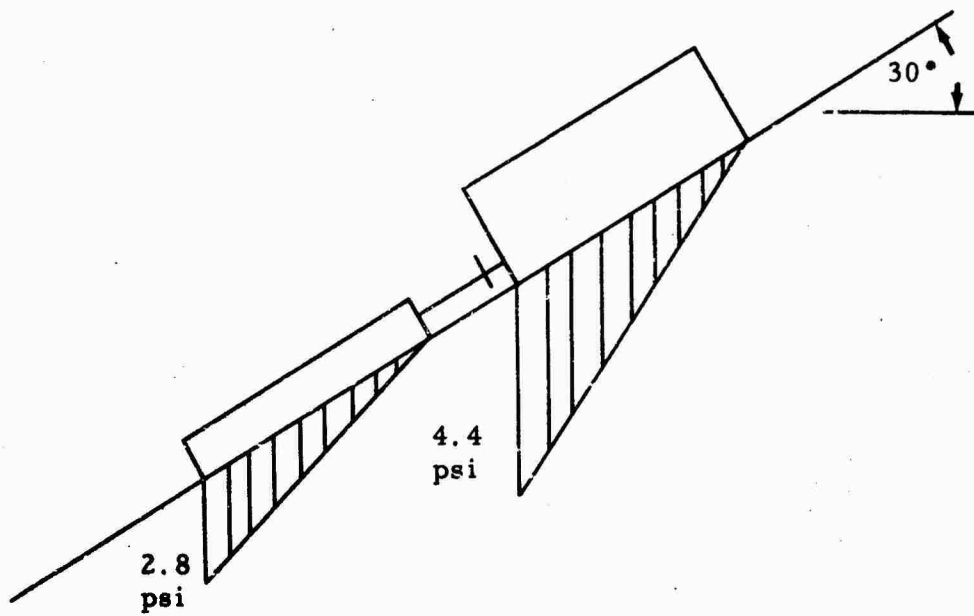Ground Pressure Distribution of M-60 on 30° Slope

FIGURE B-5.

Ground Pressure Distribution of Polecat on 30° Slope

APPENDIX C

TRACTIVE PERFORMANCE OF TRACKED VEHICLES

The drawbar-pull or net tractive effort of a vehicle is one of the most important measures of a vehicle's operational capabilities. It is directly dependent both on the strength of the soil over which the vehicle is expected to travel and on the structure of the vehicle.

Figures C-1 through C-11 are graphs showing the following:

1. The crater slope profiles.

2. The force measured at the vehicle tow pintle during the "free wheeling" winching phase.

3. The computed vehicle gross traction using the approach described on the following pages.

4. The force measured at the vehicle tow pintle during the "driven" phase. This force was the assistance required for the test vehicle to negotiate the crater slope.

These figures were drawn for only those test runs where test information was complete (Table 3 of the main report).

Interpretation of graphs C-1 through C-11 show that the difference between the total measured force (Phase I) and the computed gross traction is approximately equal to the assistance required (Phase II). If one assumes that the analytical methods are exact and identical rolling and soil resistance is encountered during Phase I and Phase II operations then the above statement is valid, however, this is not the case as will be explained in the following paragraph.

The analysis of Figures C-1 to C-4, where the vehicles needed assistance for negotiating the slope, reveals that the assumption of unchanged resistance holds true for the articulated vehicle (POLECAT), but not for the conventional

C-1

vehicle (M-113). The latter needed more assistance than the difference between the total force and the calculated traction (Figures C-3, C-4) which means that the vehicle encountered additional resistance while being driven up compared to being pulled up the slope. This additional soil resistance is accounted for quantitatively by the effect of the trapezoidal pressure distribution (Appendix B) and resulting sinkage, and qualitatively by observation of the slip-sinkage effect. This same effect on level terrain has been described analytically and experimentally by others [1,2]. The effect of slip on sinkage is most pronounced on dry granular soils [3] and the increased trim angle causes the vehicle to climb an apparent slope which is steeper than the actual surveyed slope.

In addition, it was observed during the tests that the track slip of the POLECAT was much less than that of M-113 climbing the same slope and correspondingly the attitude (trim) of the POLECAT on the slope was practically identical during Phase I and Phase II operations.

The sample calculation which follows show the method of predicting the required vehicle assistance for negotiating slopes of known magnitudes. Soil strength parameters of the slope must be known or assumed as well as vehicle dimensions and characteristics. The method consists of computing the gross tractive effort that the vehicle can develop on the slope (H) and the total resistance (R) that will be encountered. The difference (H-R) will be the assistance required if R is greater than H, or the surplus traction available if H is greater than R.

The event selected for description of prediction is the test of the M-113 on profile S 31° W (SW) of the SCOOTER crater. Data pertinent to the problem are as follows:

Vehicle Characteristics:

    Ground contact area (A)   3, 150 sq. in.

    Vehicle test weight (W)   19, 755 lbs.

Soil Characteristics:

    Slope angle (γ)   32.5°

    Soil cohesion (c)   0 psi

    Angle of internal soil friction
        (ϕ)   30°

    Sinkage parameters* k_c 0

                                  k_ϕ 3.3

                                  n   1.07

Gross Tractive Effort: $H = Ac + W \cos \gamma \tan \phi$ (1)

    $H = 19,755 \times 0.843 \times 0.577 = 9,600$ lbs.

Total resistance: $R = R_\gamma + R_r + R_c + R_\theta$ (2)

where

    1. R_γ is the resistance due to gravity as a function of the slope.

    $R_\gamma = W \sin \gamma$ (3)

    $R_\gamma = 19,755 \times 0.537 = 10,620$.

    2. R_r is the mechanical rolling resistance of the suspension components.
(60 lbs. per ton for the M-113 as per Aberdeen Proving Ground tests).

    $R_r = W \times \dfrac{60}{2000}$ (4)

    $R_r = 19,755 \times 0.03 = 590$ lbs.

    3. R_c is the resistance due to soil compaction[4].

    $R_c = \dfrac{2 b k z^{n+1}}{n + 1}$ (5)

---

* Sinkage parameters of similar sandy soils were used as vertical loading
deformation tests were not performed at the test site.

where:

b = track width

z = track sinkage

$$k = \frac{k_c}{b} + k_\phi = 3.3$$

$z = \left(\frac{p}{k}\right)^{1/n}$ (See Figure B-3 where p maximum is 16.6 psi)

z = 4.5 inches

$$R_c = \frac{2 \times 15 \times 3.3 \times (4.5)^{2.07}}{2.07} = 1,080$$

4. R_θ is the resistance due to gravity as a function of the vehicle trim angle .

$$R_\theta = W \ \sin(\ + \theta) - \sin \qquad (6)$$

θ is determined as follows:

$$\theta = \sin^{-1} \frac{z - z_o}{1}$$

where:

z_o = sinkage at front of track contact area

z = sinkage at rear of track contact area

1 = ground contact length (105 in.)

$\theta = \sin^{-1} (0.043) = 2.5°$

R_θ = 19,755 (0.573 - 0.537) = 710 lbs.

Therefore, substituting the calculated values for R_γ, R_r, R_c and R_θ into equation (2) determines:

R = 10,620 + 590 + 1,080 + 710 = 13,000 lbs.

and

$H - R$ = 9,600 - 13,000 = -3,400 lbs., the predicted assistance re-quired.

Referring to Table 3 and Figure C-3 the average measured assistance required for the M-113 to negotiate the slope profile S 31° W (SW) of the SCOOTER crater was 3,200 lbs.
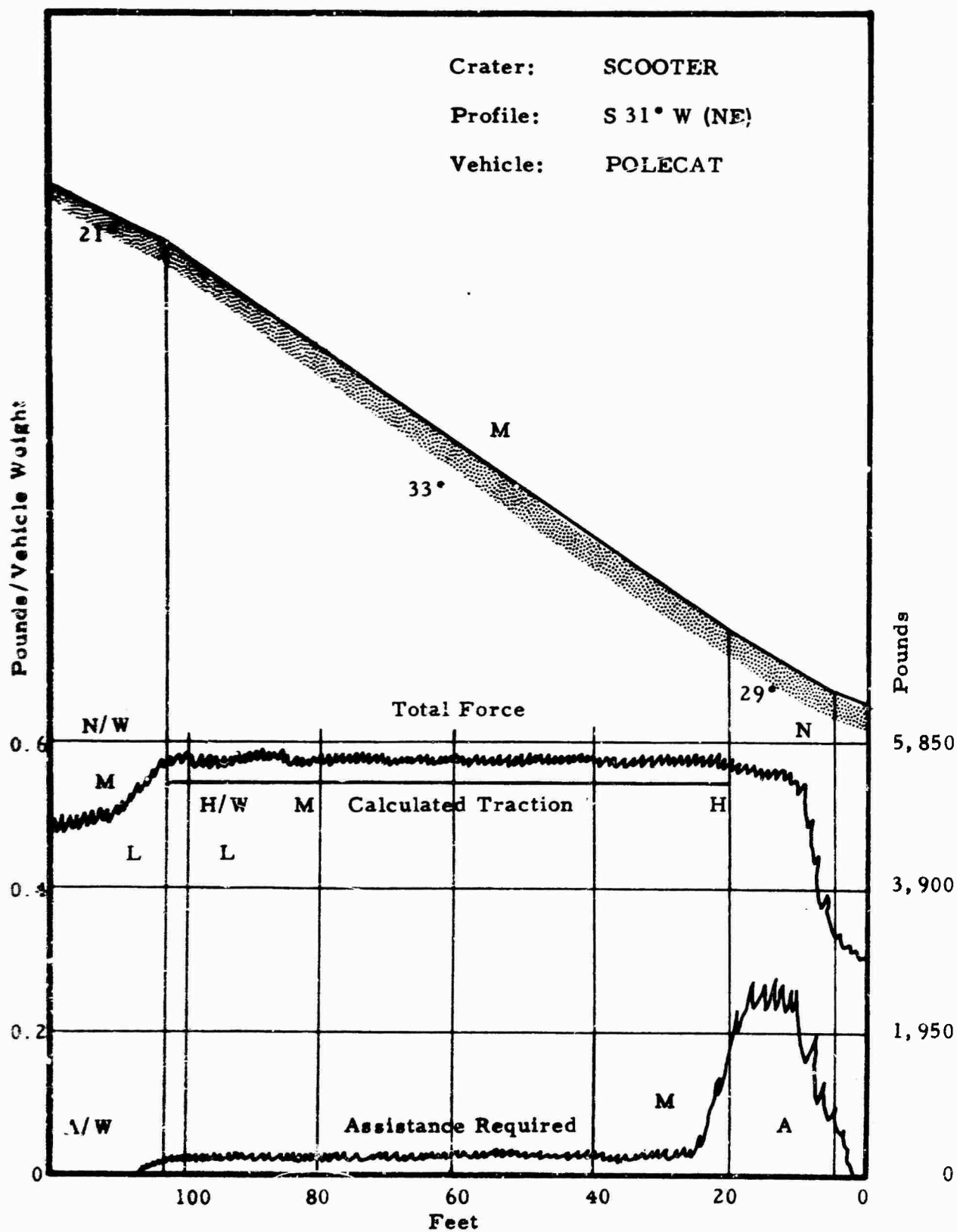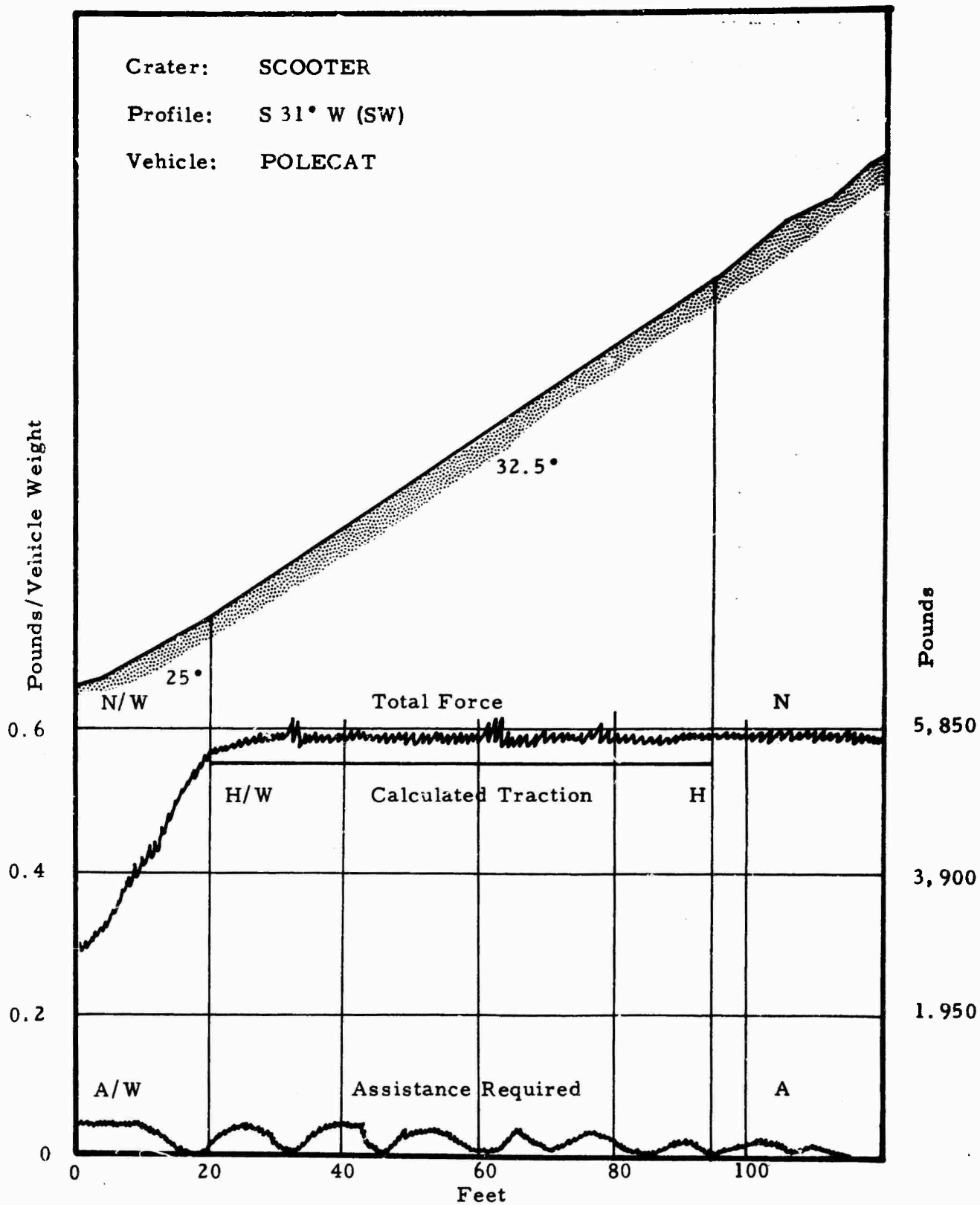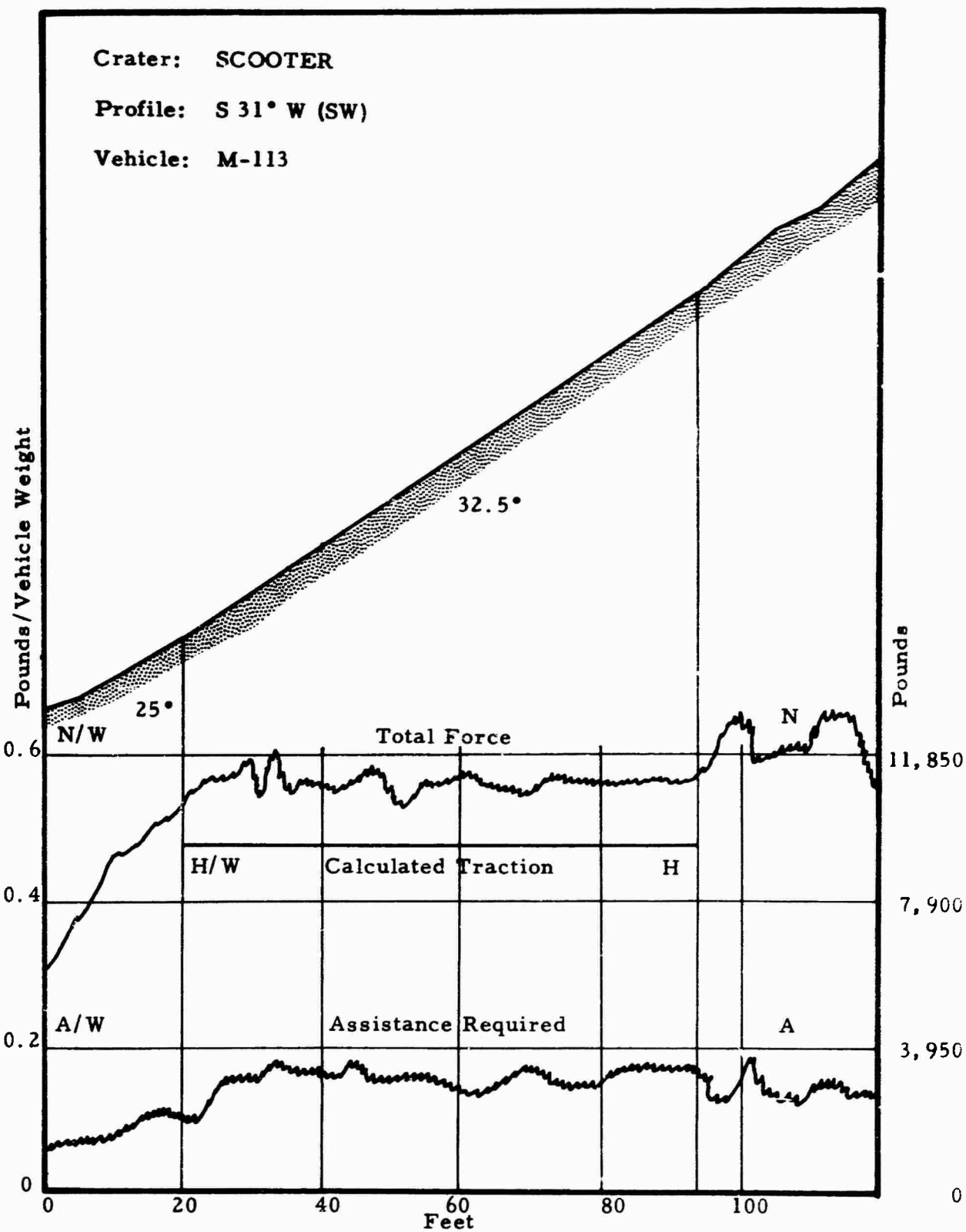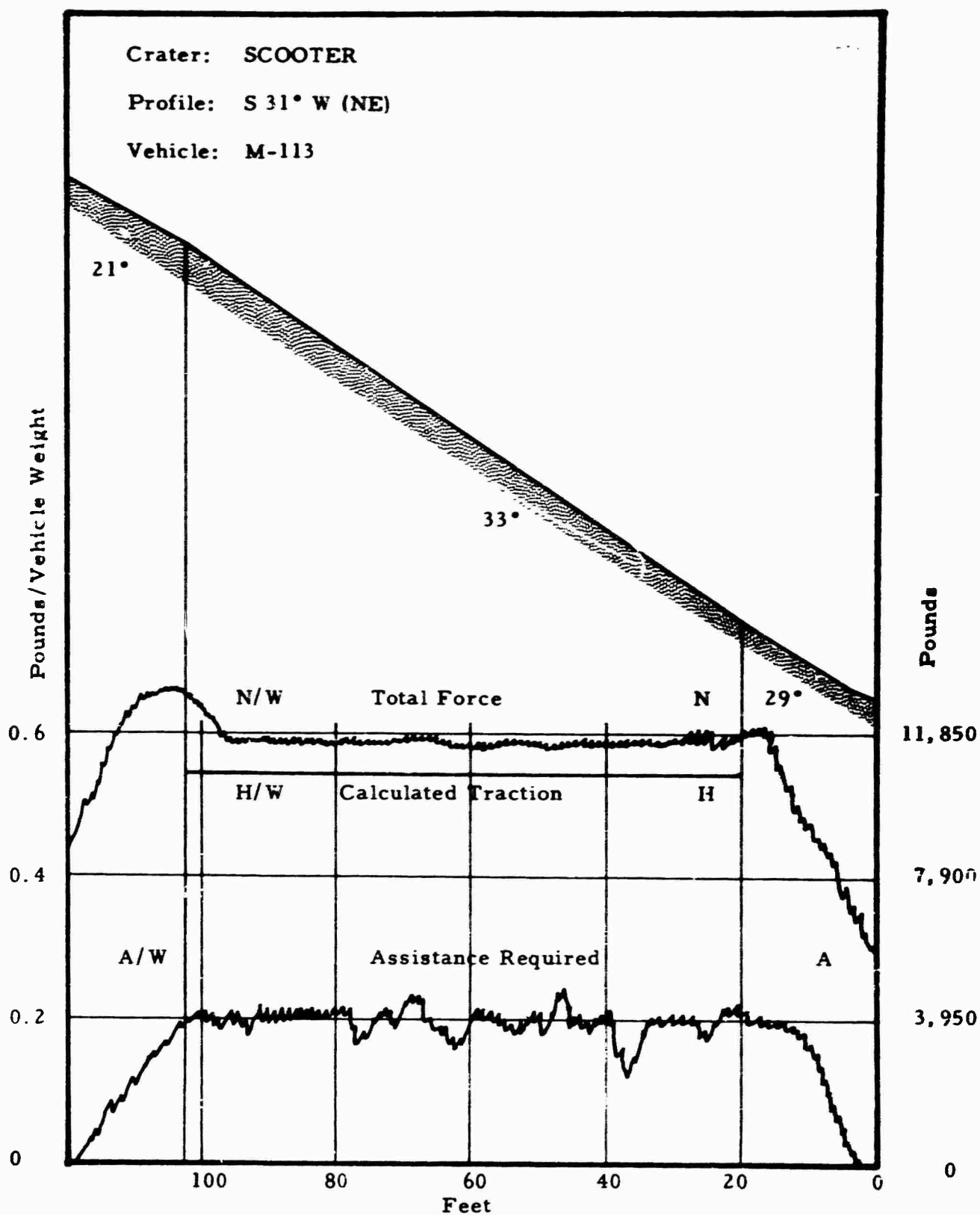
FIGURE C-1

C-6

FIGURE C-2

C-7

FIGURE C-3

Crater: SCOOTER

Profile: S 31° W (NE)

Vehicle: M-113

FIGURE C-4

C-9

FIGURE C-5

C-10

FIGURE C-6

C-11

FIGURE C-7
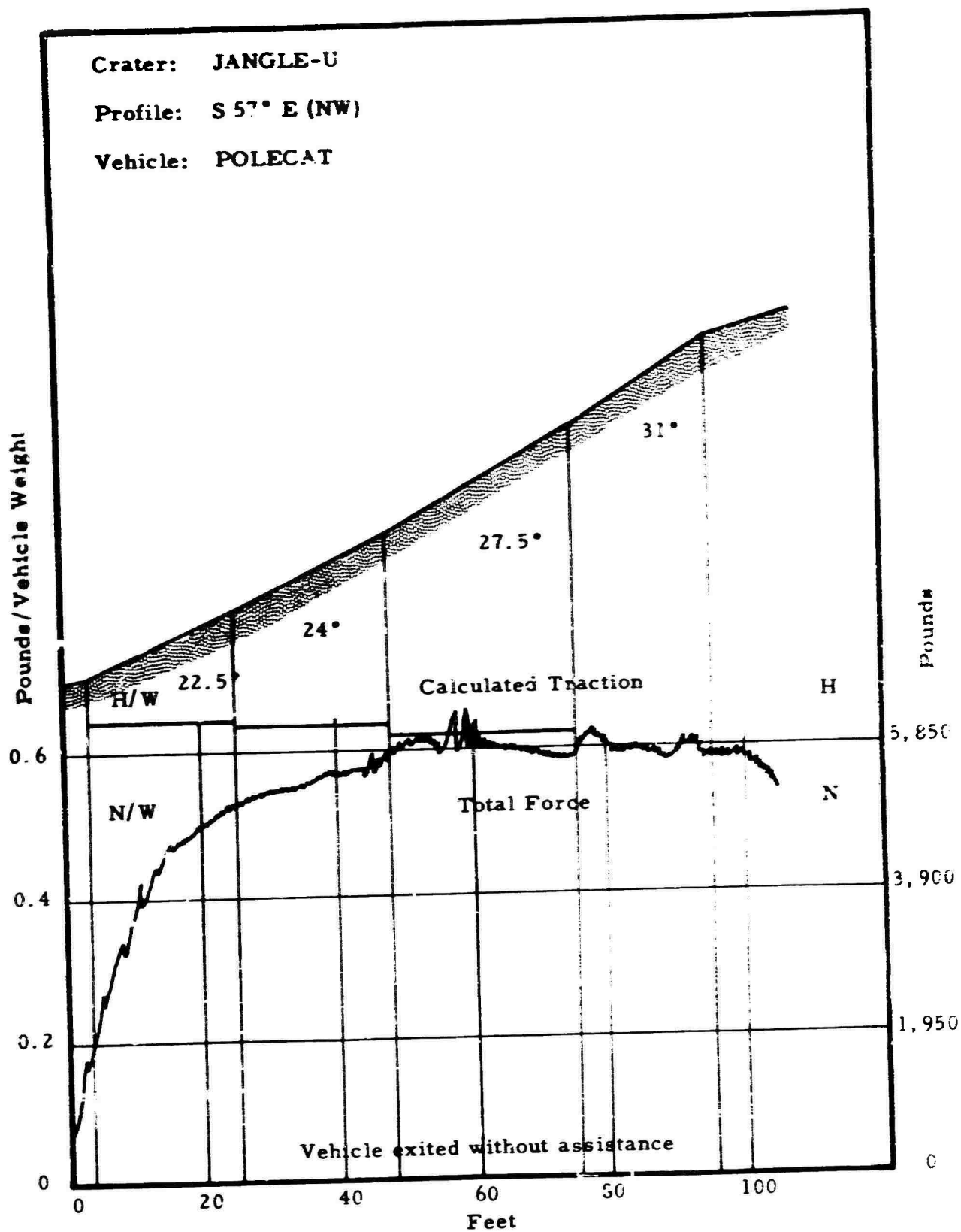
C-12

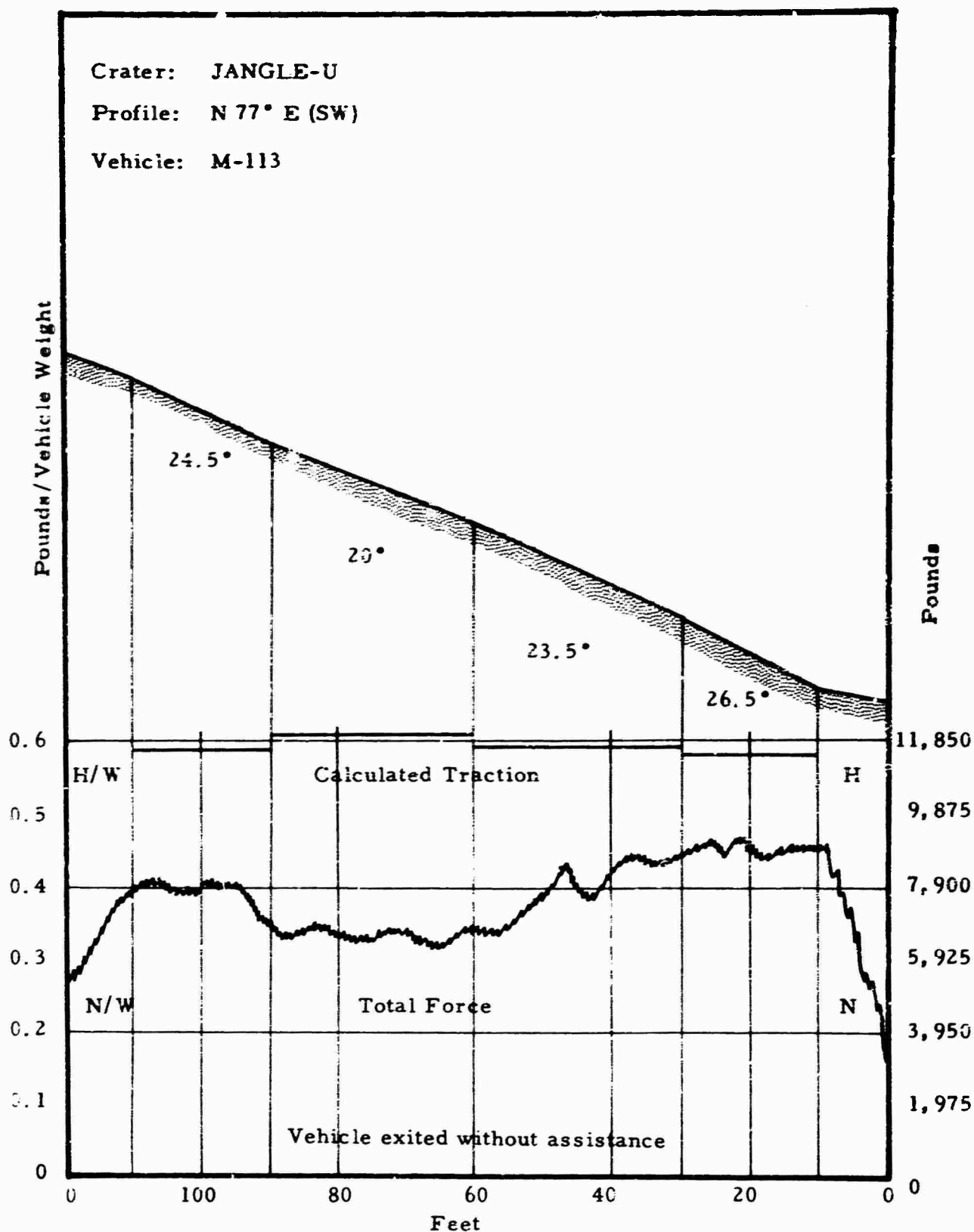Crater: JANGLE-U

Profile: N 77° E (SW)

Vehicle: M-113
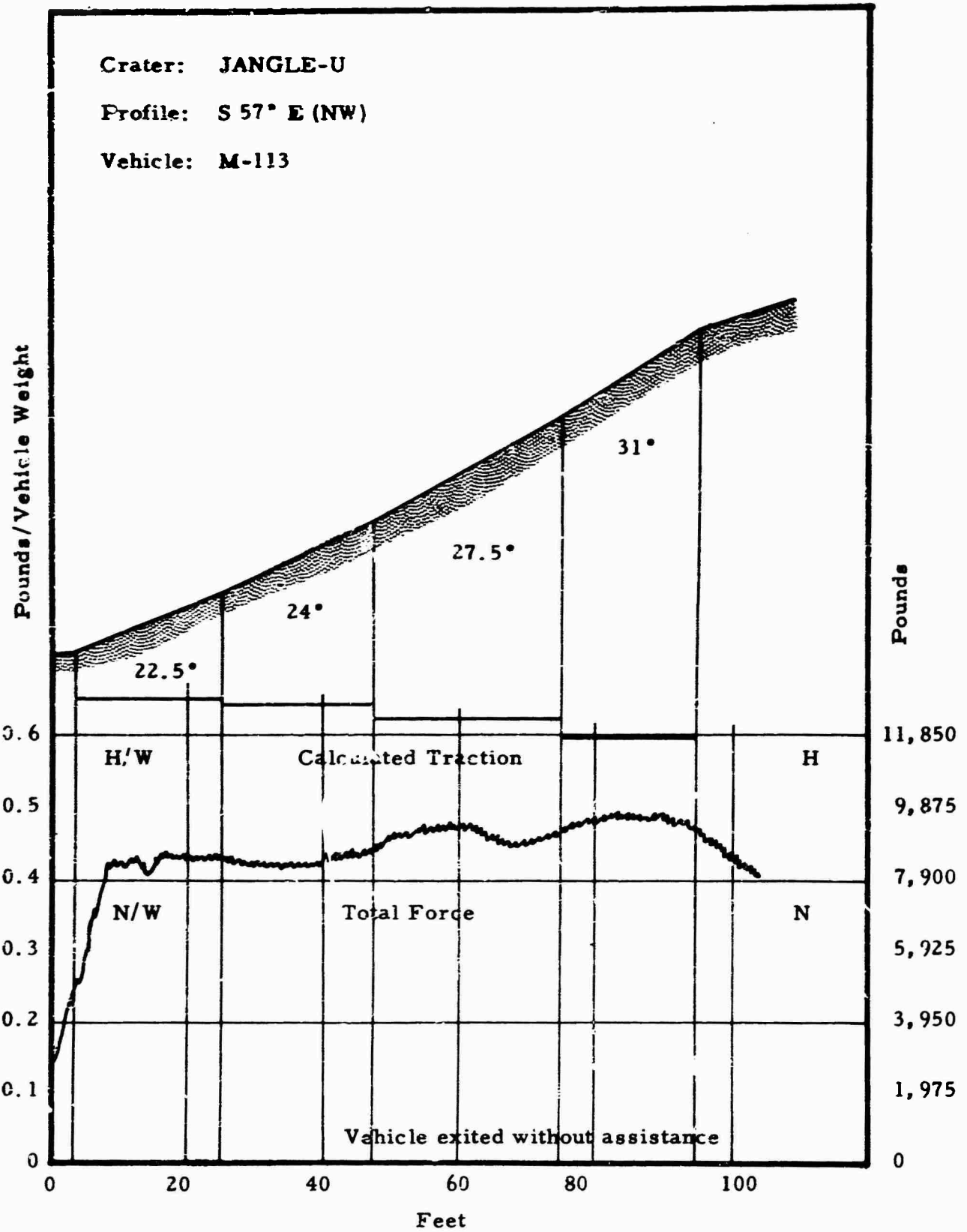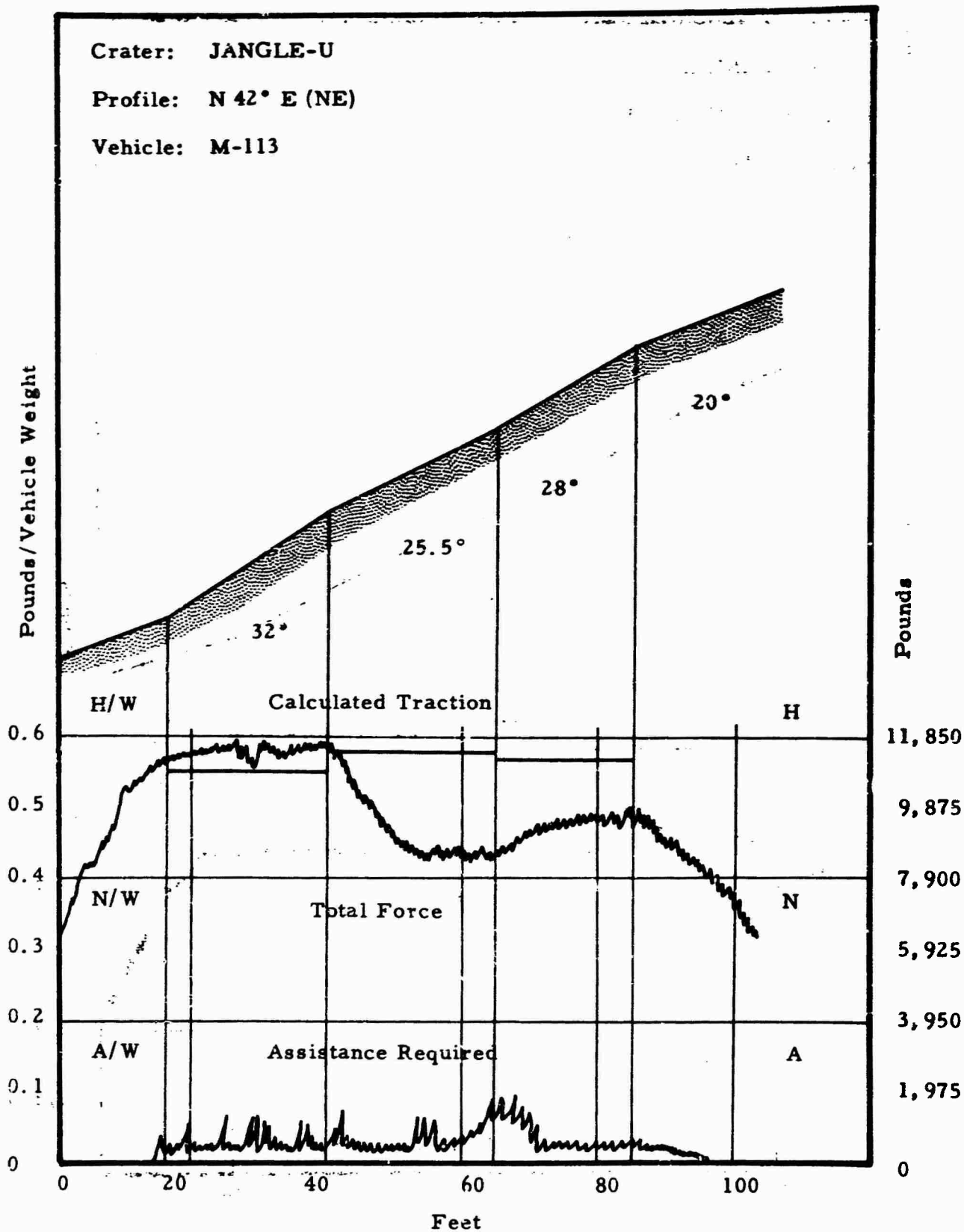
FIGURE C-8

C-13

FIGURE C-9

C-14
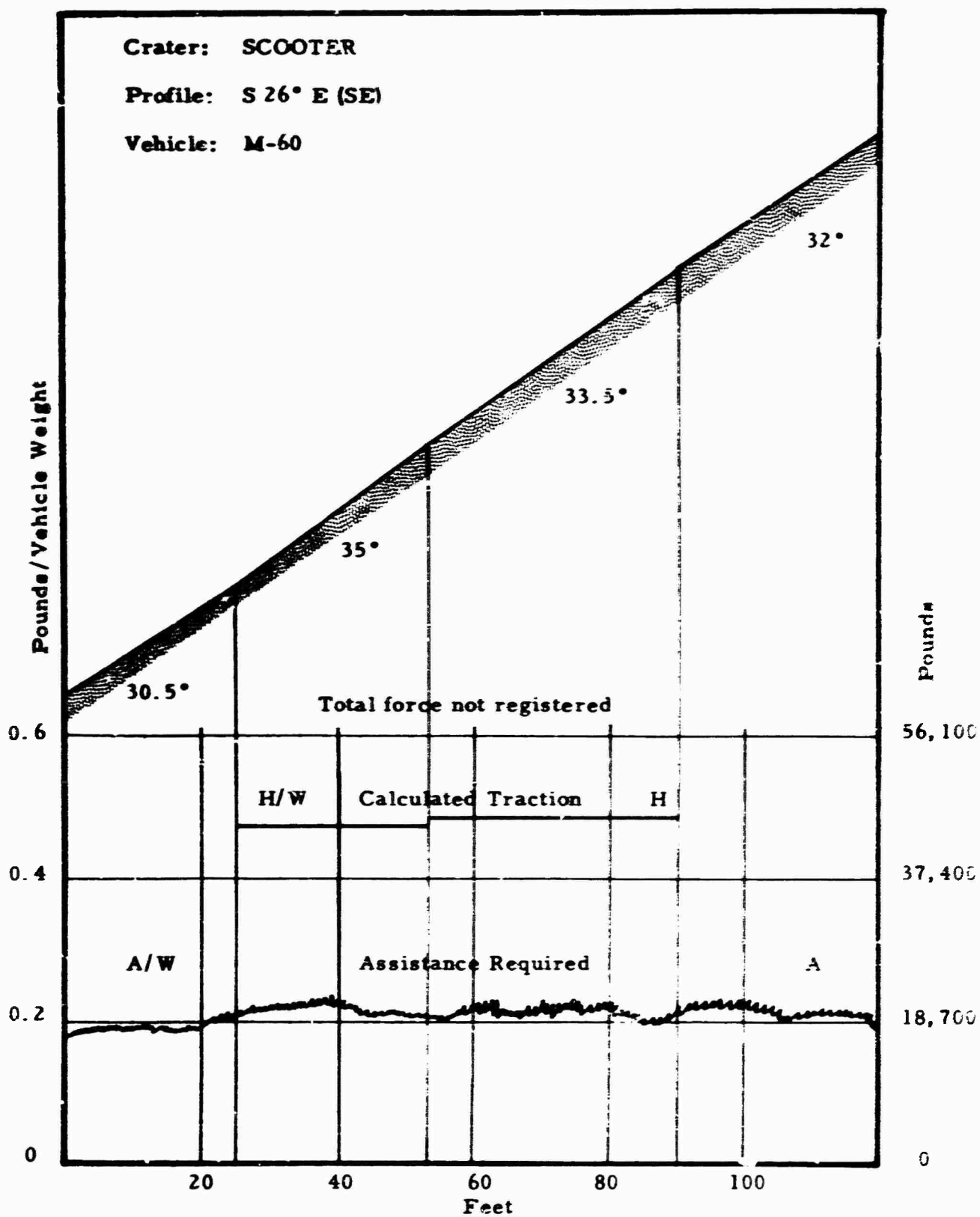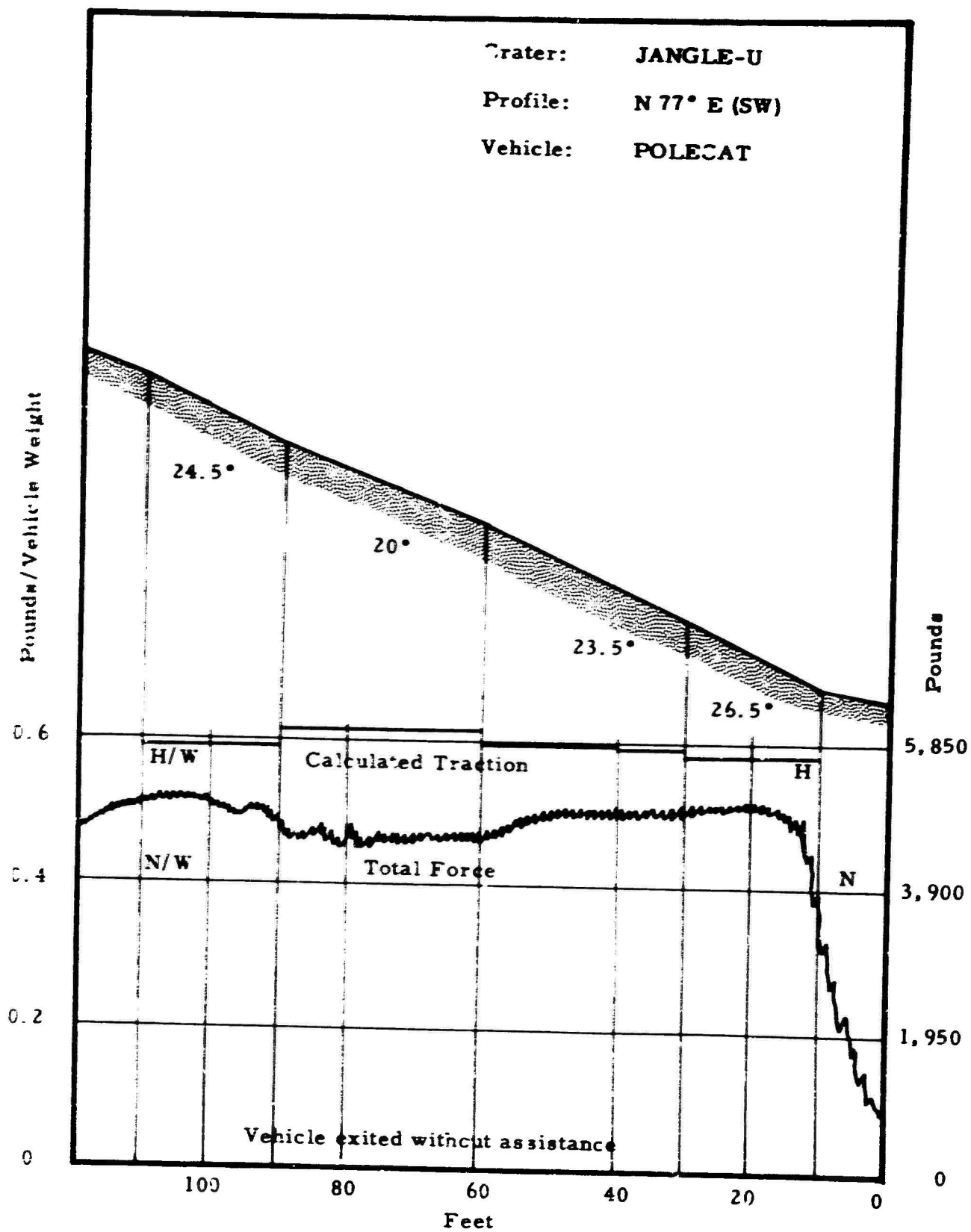
Crater: JANGLE-U
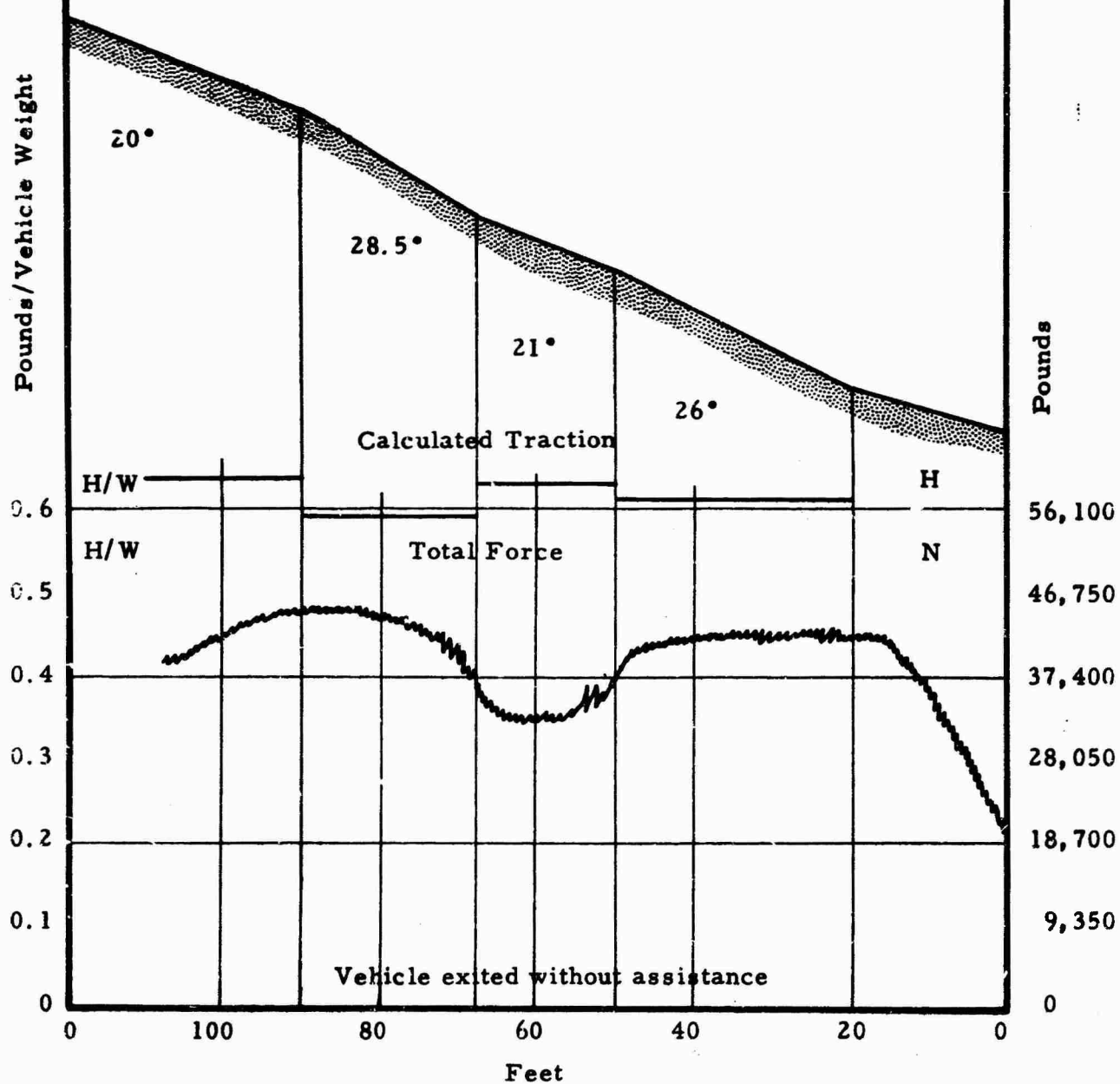Profile: N 42° E (NE)
Vehicle: M-113

FIGURE C-10

C-15

FIGURE C-11

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13. ABSTRACT

Project TANK TRAP was conducted to determine the capability of selected tactical vehicles to traverse craters typical of those which could be produced with Atomic Demolition Munitions (ADM). The vehicles included in the test program were the M-60 Tank, M-113 Armored Personnel Carrier, and an articulated two-unit general purpose vehicle called the POLECAT. Trafficability testing of these vehicles was performed in the SCOOTER crater, the JANGLE U crater, and Pre-SCHOONER BRAVO crater. The results of the research project indicate that: (1) craters formed in dry soil by the detonation of explosives at the surface or at very shallow depths of burst (down to approximately 20 ft/kt$^{1/3.4}$) do not present significant trafficability problems to tracked tactical vehicles; (2) craters formed at or near optimum depth of burst (160 ft/kt$^{1/3.4}$) in dry soil are a trafficability obstacle to tracked tactical vehicles; and, (3) craters formed in hard rock, such as basalt, cannot be negotiated by tracked tactical vehicles without major modification of the crater and/or assistance by heavy duty equipment, either mobile or fixed.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Terrain Barriers						
Trafficability						
Armor Obstacles						
Barrier Planning						
Nuclear Explosives						
Atomic Demolition Munitions						